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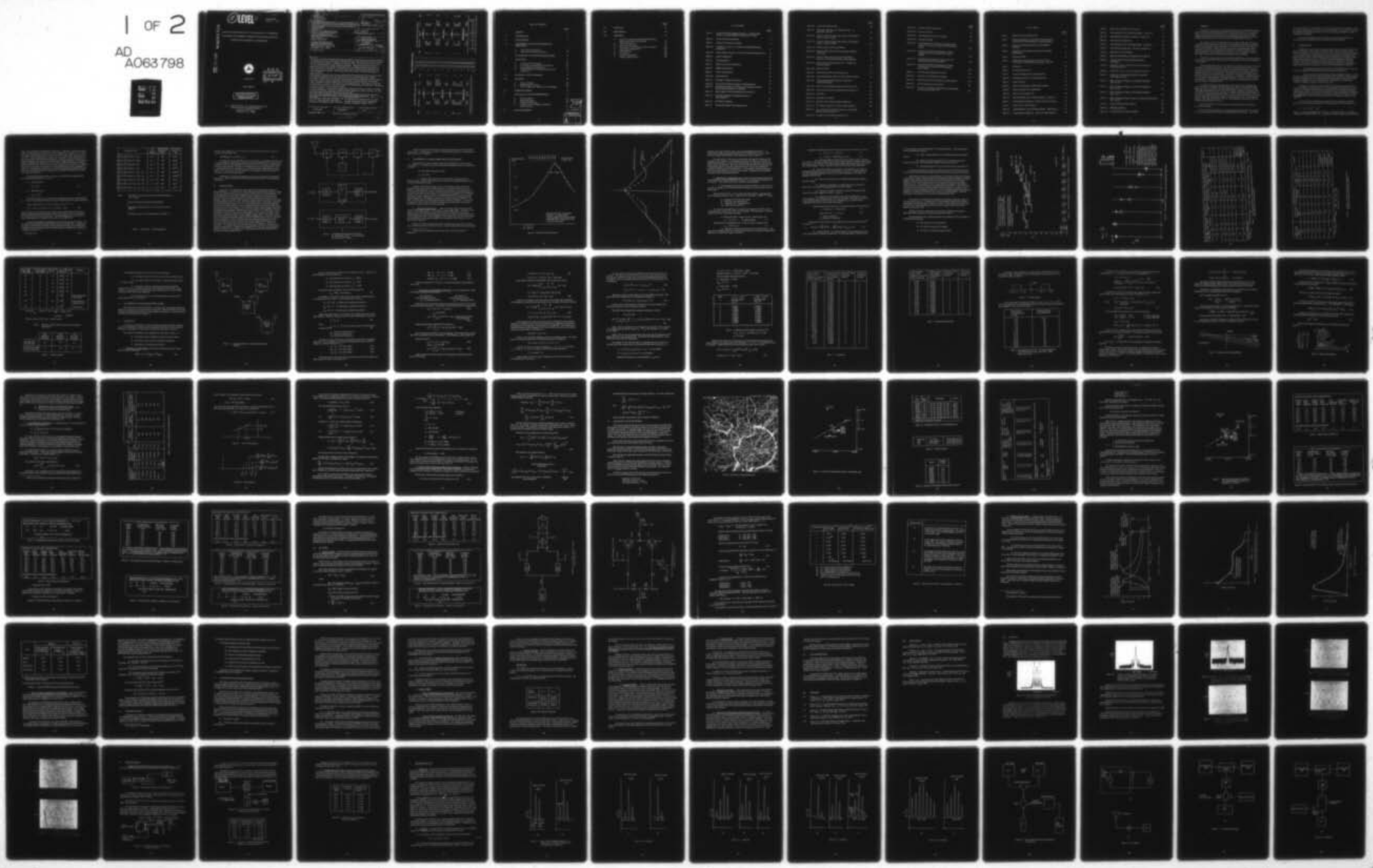

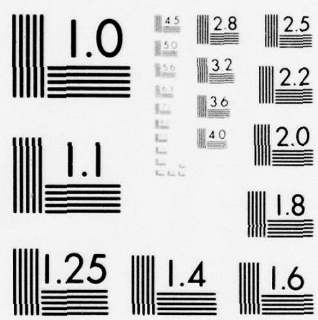
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AAF-730 - 3/78

ANALYTICAL DETERMINATION OF THE INTERFERENCE OF COMMERCIAL FM STATIONS WITH AIRBORNE COMMUNICATION AND NAVIGATION RECEIVERS AND EXPERIMENTAL VERIFICATIONS

MARCH 1978

FINAL REPORT

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Airway Facilities Service
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16. Abstract

The effects of multiple-interfering FM stations on airborne communication and navigation receivers are predicted using a third-order model of RF amplifier stage. The effects of receiver input filters and IF-filtering are modeled. Models of the detector circuits, 90 Hz and 150 Hz filters, along with the course deviation indicator (CDI) are developed. Measurement techniques useful in determining the various parameters of the model and for evaluating interference potentials are given and evaluated. The effects of different signal powers, different signal frequencies, etc. on the parameters are reported. Limits are given on the accuracy of the model and regions of validity defined.

"Brute-force" interferences due to strong interfering FM stations which saturate the front end and intermodulation distortion due to the interaction of two or more FM stations are included.

The effects of filtering due to the receiver are determined and the resulting FM-to-AM conversion analytically derived. Signal charcteristics considered for evaluating distortion include peak (cross-) modulation indices and RMS output of an envelope detector. The effects of receiver desensitation due to saturation of the front end by the interfering signals are determined. Experimental results are given to verify theoretical results.

A computer program is developed and reported which theoretically predicts the effects of multiple interfering FM stations. Input data included FM station frequencies, powers, location, etc. and the output consists of the RMS output of the receiver filters.

The results of the interference on the Course Deviation Meter (CDI) of a localizer receiver are given using single tone FM modulation of the carriers and a "White Noise" input.

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METRIC CONVERSION FACTORS

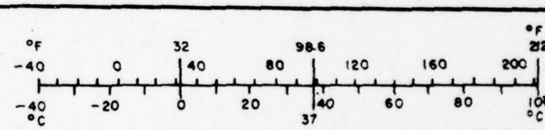
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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I SUMMARY

This paper summarizes the work performed under Contract FA77WA-3932 sponsored by the Federal Aviation Administration (FAA), Airway Facilities Service. The primary objective of the research sponsored here is the determination of an analytical model capable of predicting the effects of strong interfering FM broadcast stations on airborne navigational (specifically the localizer receiver) and communication receivers.

An analytical model of the RF-amplifier stage, using a third-order nonlinearity, of airborne communication and navigation receivers capable of predicting the effects of multiple interfering FM stations is developed. The effects of receiver input filters and IF filtering are modeled. Measurement techniques useful in determining the various parameters of the model are described and evaluated. The effects of different signal powers and different signal frequencies on the parameters are investigated. Limits are postulated on the accuracy of the model and regions of validity defined.

"Brute-force" interference due to strong interfering FM stations which saturates the front end and intermodulation distortion due to the interaction of two or more FM stations are considered.

Various signal characteristics are considered for evaluating the degree of distortion introduced by interfering FM stations. The effects of filtering due to the receiver are considered and the resulting FM-to-AM conversion analytically described. Signal characteristics considered for evaluating distortion include peak (cross-) modulation indices and RMS output of an envelope detector. The effects of receiver desensitation due to saturation of the front end by the interfering signals are considered. A substantial amount of time and effort was expended in experimental testing, on the bench, and the models were developed. Although all the experimental results are not reported here, the most important results are documented here.

A computer program was developed and is described here which theoretically predicts the effects of multiple interfering FM stations. Input data include FM station frequencies, powers, location, and other signal parameters, and calculations are made of the RMS AM modulation at the receiver filter outputs. Examples are presented which illustrate the use of the techniques developed. Tradeoff studies indicating the effects of the creation of additional FM stations and/or the results to be expected when one or more stations change their power levels, location, antenna patterns, etc. are illustrated by example. The number of FM stations that can be considered is limited only by the computing facilities available to the user.

Decision criteria that can be reliably used in predicting potential interfering sources are considered.

The results of the interference on the Course Deviation Meter (CDI) of a localizer receiver are investigated using single tone FM modulation of the carriers. Due to the

narrow bandwidths of the 90 and 150 Hz filters the CDI response due to interference would be extremely dependent on the modulation tone being assumed. To alleviate this and make the observations more general, "white noise" with a constant spectral density is used to evaluate the CDI response.

The results are applied to specific airports where interference problems have occurred and the results obtained by the theoretical model are analyzed.

II INTRODUCTION

Interference has always been an important problem area in communications systems. With increased power levels of many transmitters and the solid state design of modern receivers, interference due to high power stations driving receivers into nonlinear operation is an increasing problem. This has been the case recently where there have been many reported cases of commercial FM broadcasting station interference with airborne communication and navigational receivers. The Federal Aviation Administration (FAA) has become concerned with the increased number of reports of interference with airborne receivers. The research described in this report summarizes the efforts in developing a useful analytical model of a localizer receiver having the following two properties:

(1) The parameters required to specify the model should be easily measured or otherwise capable of being determined from manufacturers'specifications.

(2) The analytical model should be as simple as possible; however, it should be useful in predicting potential interference problems due to multiple interfering sources. In essence the objective is to develop an analytical model capable of predicting possible interference problems due to existing FM stations, additional sources beyond those currently in existence, changes in existing sources, etc.

Techniques for describing nonlinear distortion characteristics were emphasized in the early 1950's when cable television (CATV) engineering had its beginning. Further emphasis in this difficult-to-handle area were spawned by the increased use of satellite communications systems, low cost solid state receiver circuitry, etc. Many investigations have represented the nonlinear elements as having zero memory;[1-4] however, recently interest has been revived in the volterra series which was introduced by Wiener around 1942.[5]

For the particular investigation described here, it was decided to use a simple power series for the transfer characteristic for the active device in the RF amplifier, i.e.

$$e_o = K_1 e_i + K_2 e_i^2 + K_3 e_i^3 \qquad (1)$$

where e_i is the instantaneous input voltage to the active device, e_o is the output voltage of the nonlinear element, K_1, K_2 and K_3 are complex numbers describing the gain,

phase shift and distortion characteristics of the device. Although, in general, any phase angle can be specified by a proper choice of the constants K_1, K_2 and K_3, for this work we assume the phase angle on K_1 and K_2 to be 0° and the phase angle on K_3 to be either 0° or 180°. These assumptions give a simple worst case model in which the parameters of the model are easily determined by measurements. Procedures are described which can easily be applied to most receivers for determining the needed parameters. This simplified model was deemed to be adequate in view of the wide variations in receivers from manufacturer to manufacturer and even from receiver to receiver of the same type. In addition characteristics of a particular receiver will change significantly with age, temperature, AGC, etc. Measurements indicate that even with all these possible variations the results can be accurately reproduced within approximately 3 dB which is assumed to be of sufficient accuracy in practice.

The terms generated which are of concern can be identified by considering the first-and third-order terms given in (1), i.e.,

(1) Linear gain term

$$e_{o1} = K_1 e_i \tag{2}$$

(2) Third-order term

$$e_{o3} = K_3 e_i^3 \tag{3}$$

The distortion terms can be illustrated by assuming the input to be a desired signal (e_i = A cos a t) with angular frequency a and two interfering signals of angular frequencies

b and c respectively (e_{i2} = B cos b t and e_{i3} = C cos c t), i.e.,

$$e_i(t) = A \cos a t + B \cos (b t + \Phi_1) + C \cos (c t + \Phi_2) \tag{4a}$$

Using the inputs given in (4a) each of the signals can be assumed amplitude frequency or phase modulated by letting the amplitudes A, B, C, the frequencies a, b, c or the phases Φ_1 and Φ_2 be functions of time respectively. Whichever happens to be the case, we can assume the bandwidths of the signals to be B_a, B_b, and B_c respectively.

Using (4a) the possible intermodulation terms of interest are listed in Table 1. For this table, the maximum FM station bandwidth is assumed to be 240 KHz. In addition to the distortion terms listed in this table, the third-order nonlinearity will contribute self-compression or self-expansion terms at the desired frequency (a) depending on whether K_3 is negative or positive, i.e.,

$$3/4 \, K_3 A^3 \cos at \tag{4b}$$

	Possible IM Term[1]	IM Center Frequency	Maximum IM Bandwidth[2] (KHz)	Interference Caused by IM
(1)	$3/4\ AB^2 \cos[(2b-a)t + 2\Phi_1]$	2b - a	480	None[3]
(2)	$3/4\ AC^2 \cos[(2c-a)t + 2\Phi_2]$	2c - a	480	None[3]
(3)	$3/4\ A^2B \cos[(2a-b)t - \Phi_1]$	2a - b	240	None[3]
(4)	$3/4\ A^2C \cos[(2a-c)t - \Phi_2]$	2a - c	240	None[3]
(5)	$3/4\ BC^2 \cos[(2c-b)t + 2\Phi_2 - \Phi_1]$	2c - b	480	Possible[4]
(6)	$3/4\ B^2C \cos[(2b-c)t + 2\Phi_1 - \Phi_2]$	2b - c	480	Possible[4]
(7)	$3/2\ ABC \cos[(a+b-c)t + \Phi_1 - \Phi_2]$	a + b - c	480	None[3]
(8)	$3/2\ ABC \cos[(a+c-b)t + \Phi_2 - \Phi_1]$	a + c - b	480	None[3]
(9)	$3/2\ ABC \cos[(b+c-a)t + \Phi_1 + \Phi_2]$	b + c - a	480	None[3]

Notes: [1] Only IM terms which may interfere with desired frequency, a, are considered.

[2] Maximum FM signal bandwidth assumed 240 KHz.

[3] Separations between stations a, b, and c must be at least 400 KHz.

[4] Interference occurs if IM center frequency $\pm$ 240 KHz $\approx$ a.

Table 1. Possible Intermod (IM) Components.

Similarly cross-compression or cross-expansion terms generated at the desired frequency occur from the following terms:

$$3/2\ AB^2K_3 \cos at + 3/2\ AC^2K_3 \cos at \qquad (4c)$$

All other terms are assumed filtered out by the receiver. It should be noted that even if no intermodulation components generated are within the passband of the receiver as given in Table 1, there still exists a possibility of interference due to "brute-force" interference as indicated by (4b) and (4c). This type of interference shows up as cross-modulation which is a phenomenon where the modulation of an interfering carrier is impressed upon another carrier. This "brute-force" type of interference can be important when the receiver is in the presence of strong interfering signals.

Interference of the types discussed above can also have the effect of desensitizing the receiver. This is the result of the AGC reacting to the self-and/or cross-compression of the carrier.

III RECEIVER MODEL

In general it is the RF amplifier stage where most of the nonlinear distortion is generated; however, it is possible and in the presence of extremely strong interfering signals it would be expected that the mixer stage would contribute to the nonlinear distortion. In this investigation we assume the RF-amplifier to be the significant source of nonlinear distortion; therefore, an adequate model of this stage is necessary and sufficient for our purposes. Figure 1a indicates a block diagram of a typical receiver and Figure 1b the model of the RF-amplifier used in this work, where the nonlinear device input-output is specified by the transfer characteristic given in (1). The input filter block is assumed to represent the effects of the input circuitry, while the output filter block represents the effects of the output circuitry of the RF-amplifier. In the frequency domain input and output attenuations are represented by $a(\omega)$ and $\beta(\omega)$ respectively. If one assumes all the nonlinear terms to be generated in the RF-amplifier, then the model shown in Figure 1c can be assumed. Using this model the input is assumed to be the RF-amplifier input (voltage at the output of the receiver antenna) and the output is the IF-amplifier voltage output. In this case the output filter will include the attenuation properties of the RF-amplifier output circuitry, the mixer and the IF-amplifiers. Since no distortion terms are assumed generated with the mixer stage, the effects of this stage is assumed to be a linear frequency translation and all calculations and modeling can be done at either the IF or RF frequency, whichever is convenient. This representation has significant advantages in practice in determining the parameters experimentally. Methods were developed which allow the overall parameters specified in Figure 1c to be determined by simply monitoring the AGC voltage with an interfering and desired signal present.

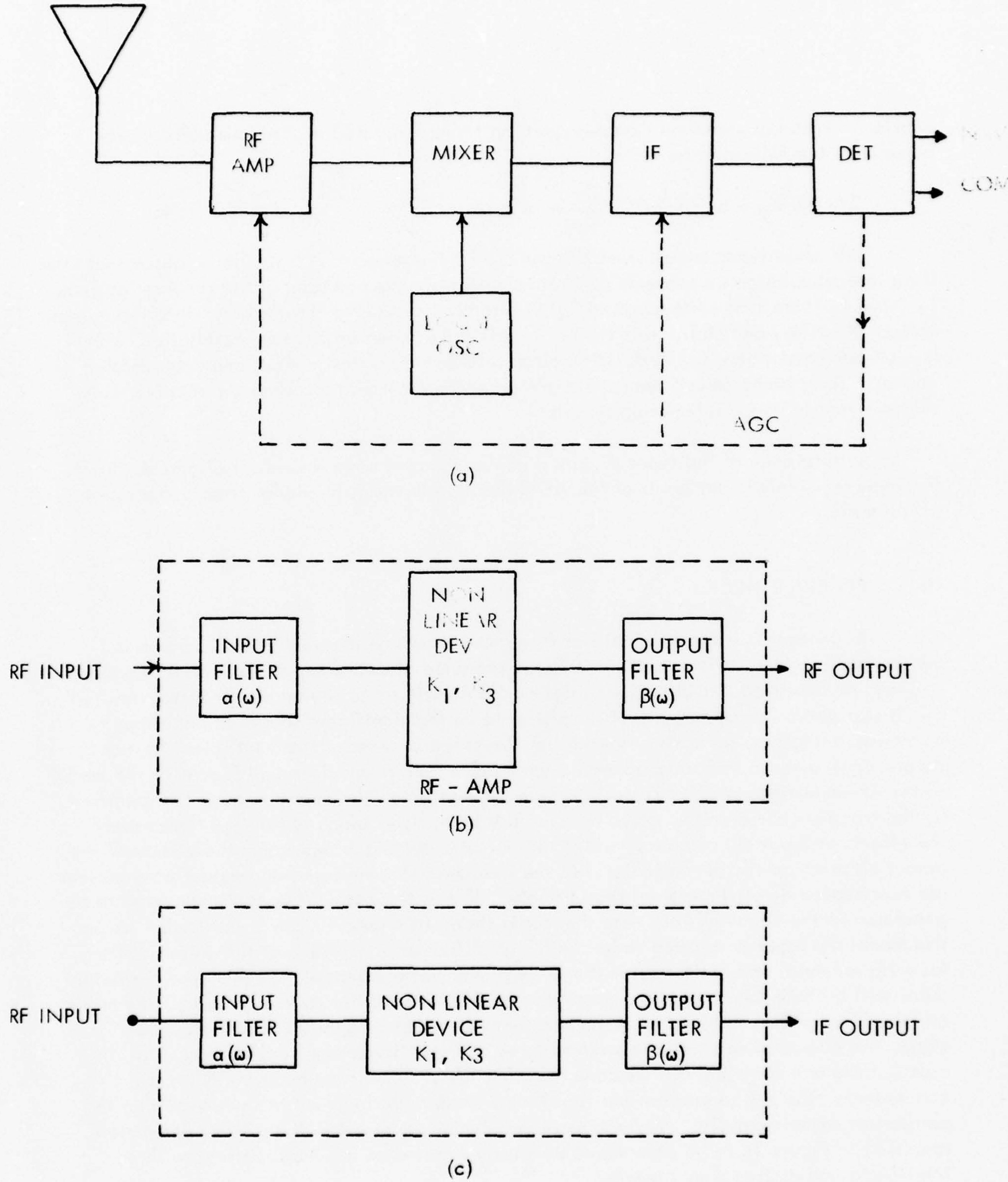

Figure 1. (a) Simplified Block Diagram of Receiver. (b) RF-Amplifier Model. (c) Overall Model from RF-Input to IF Output.

Using the model specified by Figure 1b requires measurements of the RF-amplifiers output, which in general are very sensitive measurements due primarily to loading effects. Both methods were investigated.

IV MEASUREMENTS OF MODEL PARAMETERS AND APPLICATIONS

Application of the receiver model requires that the signal level at the receiver input be known. In addition the following information regarding the receiver characteristics is needed:

(1) Input-filter characteristics $a(\omega)$.

(2) K_1 and K_3

(3) Output filter characteristics from the RF to the output of the IF-amplifier stages. With this information one can calculate the resulting distortion terms at the output of IF-amplifier stages.

With this information the model can be used to predict the output from the IF-amplifier and the output of the envelope detector. In a later section of this report an analytical model of the CDI circuitry is described and developed. Since the interest in this research was primarily concerned with the interference of commercial FM broadcasting stations with aircraft localizer receivers, the examples and applications are in this area. The receiver used for experimental work was Nav 11 localizer receiver manufactured by NARCO Corporation. The frequency range of the localizer receiver is 108 MHz to 118 MHz, while the commercial FM broadcasting band is from 88 to 108 MHz. As a result of the adjacent location of these two frequency bands, both intermodulation distortion and "brute force" type interference must be considered.

A. Input Filter Characteristics. Figure 2 indicates a plot of the receiver RF-amplifier input filter function.* The receiver is tuned to 108.5 MHz. The effects of the output circuitry of RF-amplifier can be combined with the IF-amplifier and detector characteristics so that one overall attenuation function is all that is required and since most of the bandlimiting is done in the IF-amplifier, these characteristics are the most important. These characteristics are normally available from manufacturers' data; however, if not, they are easily measured.

Figure 3 illustrates the overall attenuation characteristics of the NAV 11 localizer receiver from the IF input to the detector output. Some discrepancies were observed between

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*The measurement techniques used to obtain these results are described in Appendix B.

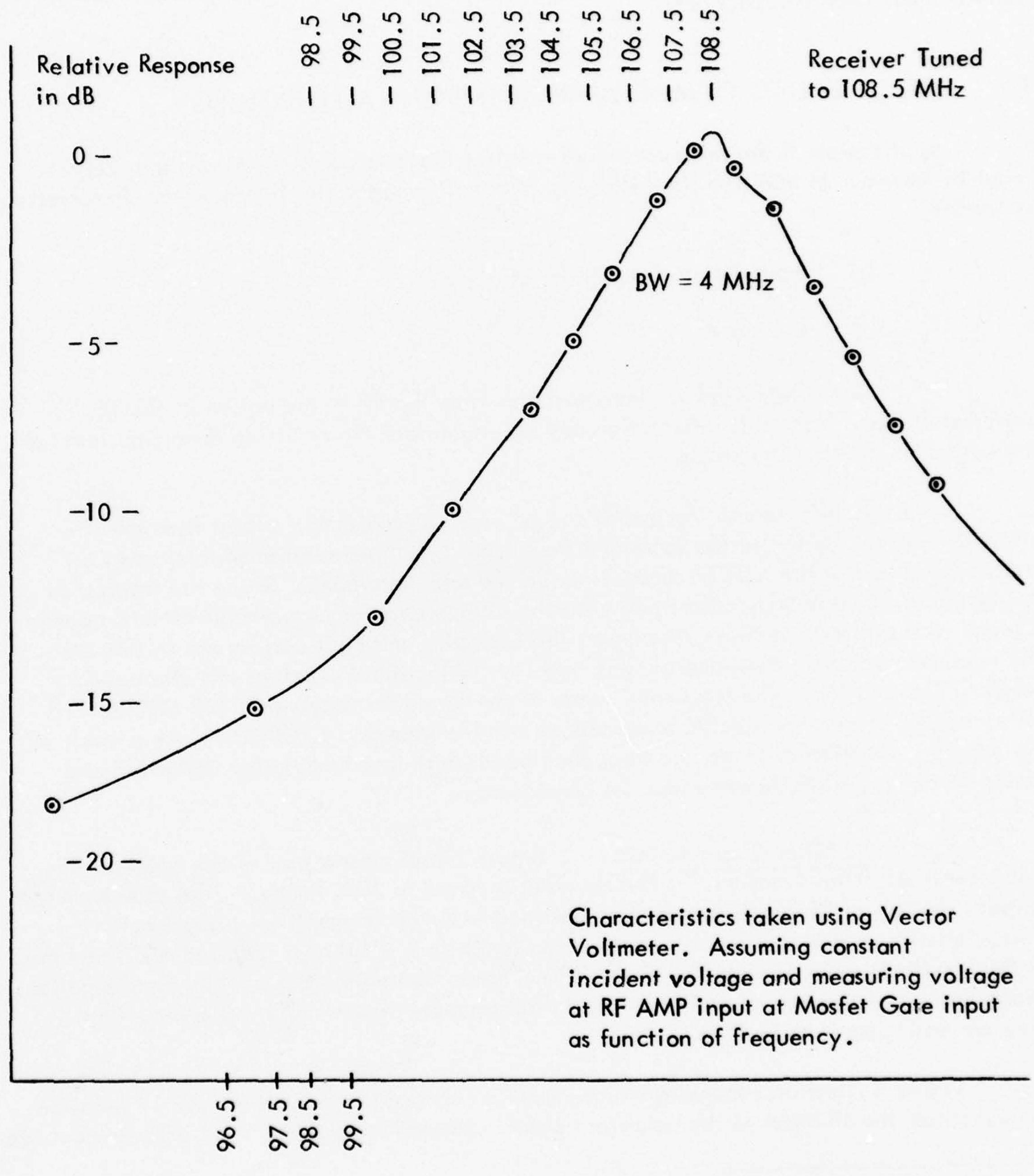


Figure 2. RF Input Filter Characteristics.

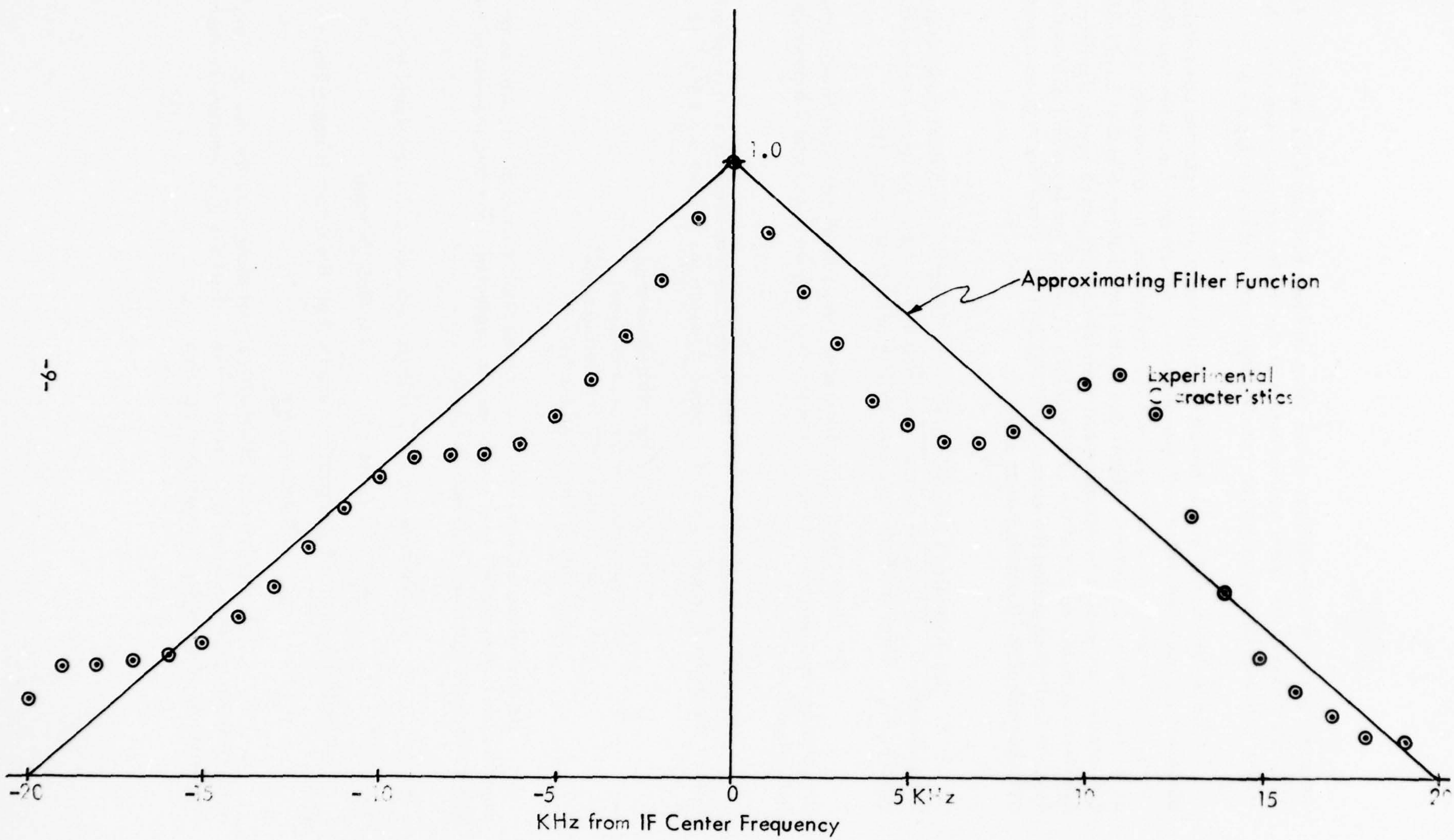


Figure 3. Relative IF and Detector Response.

measured values and theoretical values using an Ideal Bandpass Charcteristic. To alleviate this a higher order approximation of the IF characteristics was used. In particular a triangular approximation was developed and is shown in Figure 3.

Since the interest in this research was primarily with regard to commercial FM broadcast station interference with navigational receivers and due to the fact that the navigational information is conveyed via AM techniques, the attenuation characteristics of the receiver are important. This is due to the fact that the effect of bandlimiting the FM interfering signal is to introduce AM modulation on it which causes significant interference at the output of the AM detector. A considerable amount of experimental data was collected during the execution of this project. Appendix A gives representative spectral plots illustrating these effects.

B. Determination of Model Parameters. Using the analytical model requires that the parameters K_1 and K_3 be determined. Actually it is only necessary to determine the ratio K_3/K_1. Three methods were used to determine these parameters.

(1) Gain Compression Technique (two-carrier method) - in this scheme two sinusoids are applied, one at the desired receiver frequency (a) and the other an interfering signal.

Using (1) and (4c) (with c = 0) the third-order term predicts a cross-modulation term at the desired frequency which is proportional to the product $K_3\ AB^2 a^2$ (b) where,

K_3 = parameter of the third-order model
A = amplitude of the desired signal
B = amplitude of the interfering signal
$\alpha(\omega)$ = input filter characteristic

The desired signal amplitude A is assumed small compared with AB^2 so that the contribution due to the A^3 term in (4b) can be neglected. The measurement of the ratio using this technique was performed as follows:

(a) Measure the AGC voltage with only a desired signal input,

$$e_i = \sqrt{2}\, A \cos a\, t \qquad \text{(A is RMS Voltage)} \tag{5}$$

Neglecting the self-compression term in (4b), the output is approximately

$$e_o = \sqrt{2}\, AK_1 \cos a\, t \tag{6}$$

(b) Applying an interfering signal along with the desired signal. The result of the interfering signal is to compress the desired signal or expand the desired signal depending on whether K_3 is negative or positive.

Using (4c) and choosing those terms of interest at the receiver frequency we have,

$$e_i = \sqrt{2}\, A \cos a\, t + \sqrt{2}\, B \cos b\, t \qquad (7)$$

$$e_o = \sqrt{2}\, AK_1 \,(1 + 3B^2 \alpha^2 (b)\, K_3/K_1) \cos at \qquad (8)$$

(c) Increase the desired signal level until the AGC voltage is the same as in step (a). The amount of dB increase in desired signal required to bring the AGC voltage back to the value in step (a) is the amount of gain change of the desired signal level due to the interfering signal. Hence, using (6) and (8) the ratio K_3/K_1 is easily determined.

(2) Two-carrier method with modulation - this method uses an interfering AM-modulated signal along with a desired CW signal as the input. By measurement of the cross-modulation obtained the ratio of K_3/K_1 can be determined. The steps in the procedure are as follows:

(a) With a desired signal and no interfering signal applied, measure the AGC voltage.

(b) Applying a combination of a desired signal and an interfering signal with a known percent modulation, observe the AGC voltage.

(c) Increase or decrease, whichever is required, the desired signal level until the AGC voltage is the same as in step (a).

(d) Measure at the IF-amplifier output the AM sidebands due to the cross-modulation of the interfering signal on the desired signal. This gives the amount of cross-modulation obtained which can be used to determine K_3/K_1 (note that cross-compression of the carrier must be taken into account).

Mathematically the procedure can be described as follows: Let the input be

$$e_i = \sqrt{2}\, A \cos a\, t + \sqrt{2}\, B\, (t) \cos b\, t \qquad (9)$$

where $B\,(t) = B_1\, [1 + m \cos \omega_m t]$ (10)

m = percent modulation
ω_m = frequency of modulation

Considering the third-order term and neglecting the terms containing m^2 and B^2 the result is

$$e_o = \sqrt{2}\, AK_1\, [1 + 3\frac{K_3}{K_1} \alpha^2 (b)\, B_1^2 + 6\frac{K_3}{K_1}\alpha^2 (b)\, B_1^2\, m \cos \omega_m t] \cos a t \qquad (11)$$

(3) Intermod Method - this method is based on simply measuring the level of an intermodulation component generated by two interfering signals of frequencies such

that they produce an intermod component at the desired frequency. These measurements can be accomplished as follows:

(a) Apply a desired signal of known amplitude and measure the AGC voltage.

(b) Without a desired signal apply the two interfering signals and adjust the amplitudes such that the AGC voltage is the same as in step (a).

(c) The desired signal level in (a) is then equal to the intermod level.

The three methods above can also be modified such that the AGC voltage is held constant and the levels at the IF-amplifier output are measured using a spectrum analyzer.

Specifying a receiver by such a model brings up the question of how much variation in ratio K_3/K_1 is there. Most past work has been concerned with the modeling of wideband amplifiers where problems with variations in the AGC characteristics are not present. In addition, the ratio K_3/K_1 could be a function of input signal levels and input signal frequencies, etc. A considerable number of experimental measurements were obtained using the NAV11 localizer receiver to investigate these characteristics. Figure 4a shows the results obtained using the intermod method. These results give an indication of the variations in 3 K_3/K_1 (expressed in dB) as a function of the intermod generating frequencies. Indicated on this figure are the signal levels of the two interfering signals. Figure 4b indicates the results obtained as a function of interfering signal level.

If the model is consistent all three measurement techniques should give relatively the same results for K_3/K_1. Comparison of the results obtained using the three different measurement techniques are given in Tables 2, 3 and 4. These results again indicate that the ratio K_3/K_1 can be assumed essentially constant in regions where the third-order model can be assumed valid.

Although the amount of data given in these tables is limited, some important observations and conclusions can be made and are given in Table 5.

The measurements seem to indicate that there are variations which can probably be attributed to the following:

(a) The sensitivity of the measurements.

(b) The receiver characteristics changing.

(c) The order of the model not being sufficient.

Notes:

1. Signal levels required to give the data points are given in parentheses. The first is the b frequency signal level in dBm incident, the second is the c signal level.
2. Intermod level produced by data points is -60 dBm (220 μv) AGC fixed (determined by intermod only).
3. Filter function used to calculate $3K_3/2K_1$ is shown in Figure 2.

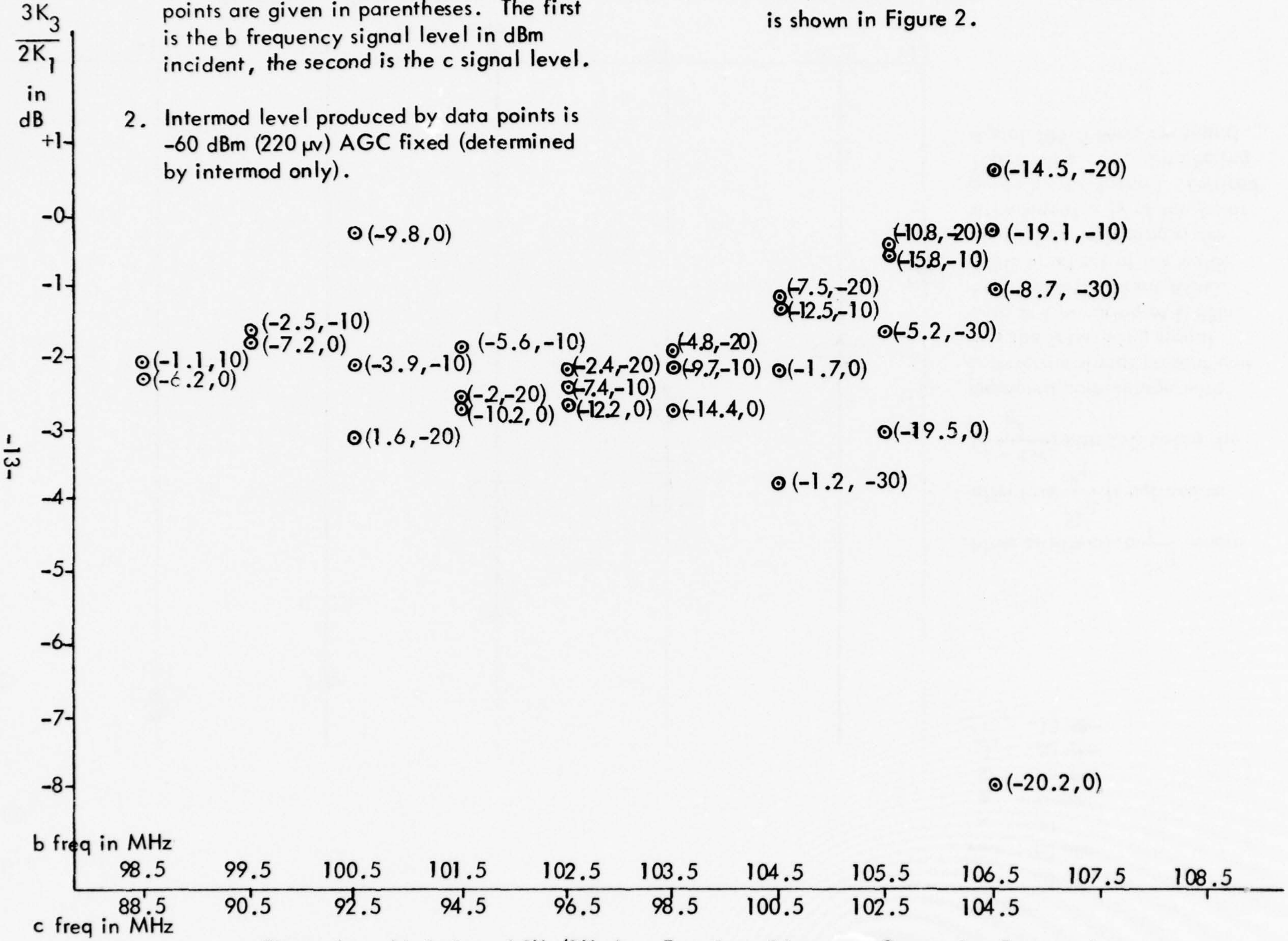
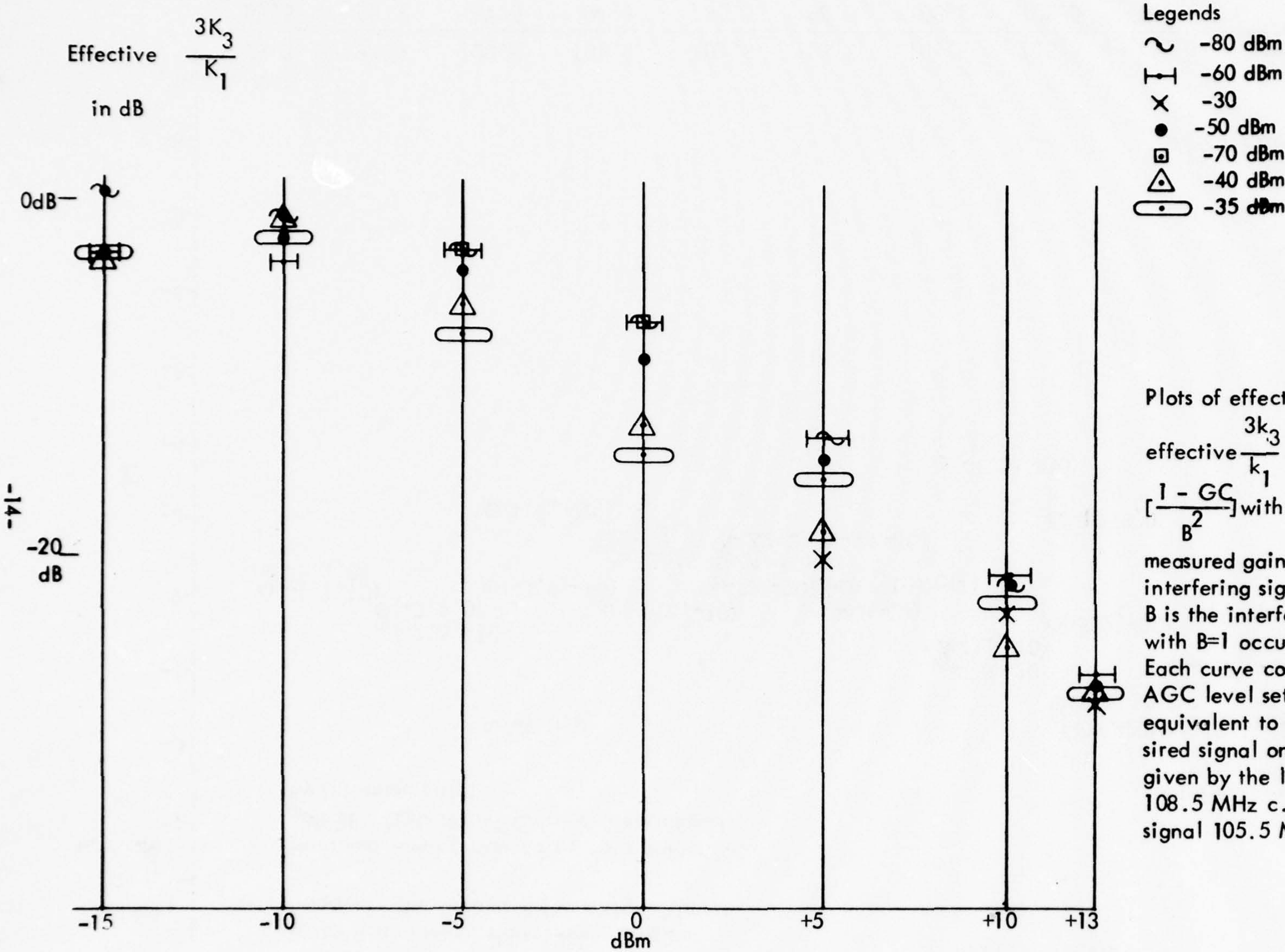


Figure 4a. Variation of $3K_3/2K_1$ As a Function of Intern... Generating Frequencies.



Plots of effective $\frac{3k_3}{k_1}$ where effective $\frac{3k_3}{k_1}$ is defined as $[\frac{1 - GC}{B^2}]$ with GC being the measured gain charge with interfering signal present and B is the interfering signal with B=1 occuring at 0 dBm. Each curve constant AGC. AGC level set at the value equivalent to having a desired signal only of the level given by the legend. Desired 108.5 MHz c.w. Interfering signal 105.5 MHz cw signal.

Figure 4b. Plots of Effective $3K_3/K_1$ as a Function of Interfering Signal Level.

Desired Signal Level (-dBm) 108.5 MHz	Interfering Signal Level (-dBm) B 105.5 MHz	Modulation* on Interfering Signal (-dB)	Cross Modulation* of desired signal measured (-dB)	Gain Compression of desired signal measured (-dB) GC	AGC (Volts)	$\frac{3K_3}{2K_1}$** (dB)	Comments
80	5	14	22 to 23	3.2	1.703	-4.2 to -5.2	
70	10	14	28 to 29	1.3	1.497	1.7 to 0.7	
60	10	14	27 to 27.5	1.1	1.373	2.9 to 2.4	
50	10	14	27.5 to 28	0.7	1.295	2.8 to 2.3	
40	10	14	28	1.0	1.245	2.0	
30	10	14	28.5	0.3	1.211	2.2	
20	10	14	21.9	-1.4	1.189	10.5	Model not valid at the signal level
10	10	14	19.6	-1.2	1.168	12.6	Model not valid

*Carrier to sideband level

**$3/2\ K_3/K_{1\ dB}$ = Cross Modulation*$_{dB}$ - $2a(b)_{dB}$ - $2B_{dBm}$ - Modulation* on interfering signal$_{dB}$ + GC_{dB} - 12 dB

Table 2. $3K_3/2K_1$ Determined by Cross-Modulation Measurements with 10 KHz AM Tone Modulation on Interfering Signal.

B (105.5 MHz Signal Level) (-dBm)	C (102.5 MHz Signal Level) (-dBm)	Measured Equivalent Desired Signal Level of IM (-dBm)	AGC Voltage (Volts)	$\frac{3K_3}{2K_1}$ (dB)*	Comments
22.5	20	80	1.717	3	
18.5	20	70	1.499	5	
17.0	10.0	60	1.376	2.	
11.7	10.0	50	1.299	1.4	
7.5	10.0	40	1.248	3.0	
4.9	10.0	30	1.217	7.8	Model probably not valid.
6.	0.0	20	1.196	10.0	Model probably not valid.
0.0	0.0	10	1.175	8.0	Model probably not valid.

$$* 3K_3/2K_{1_{dB}} = \text{IM Measured}_{dBm} - 2\,a(b)_{dB} - a(c)_{dB} - C_{dBm} - 2B_{dBm}$$

where $2a(b) + a(c) = -18$ dB

Table 3. Parameters of Model Determined by Intermodulation Technique. Intermod at 108.5 MHz (2B-C)

Desired Signal Level (-dBm) 108.5 MHz	Interfering Signal Level (-dBm) B 105.5 MHz	Gain Change GC(-dB)	AGC (Volts)	$\frac{3K_3}{2K_1}$ * (dB)	Comments
80	10	1.2	1.727	5.2	
70	10	1.1	1.498	4.5	
60	10	0.9	1.376	2.9	
50	10	1.0	1.299	3.6	
40	10	0.8	1.250	1.9	
30**	10	-	1.218	-	None measured by this method.
20**	10	-1.8	1.198	-	Gain expansion-model not valid
10**	10	-1.2	1.177	-	Same as above

$$*3/2\ {K_3/K_1}_{dB} = 20 \log (1 - GC') - 2B_{dBm} - 2a(b)_{dB} - 6dB$$

$$\text{where } GC' = 10^{GC_{dB}/20}$$

**Localizer signals of these levels would be unusual.

Table 4. Parameters of Model Determined by Cross-Compression Measurements.

	Gain Compression Technique	Cross-Modulation Technique	Inter-Modulation Technique
Average Value $3K_3/2K_1$ (dB)	3.6	2.9	2.6
Maximum deviation from the mean (dB)	1.7	2.4	2

Table 5. Summary of Results.

The following conclusions can be drawn from the data obtained:

(a) The model is useful for localizer signal levels at -30 dBm or lower.

(b) The model is useful for "brute-force" interfering FM signal levels of - 10 dBm or lower.

(c) The model is useful for interfering signals of the appropriate frequencies such that an intermod is generated with strength of -30 dBm or less. From Table 3 it is observed that this requires input signal levels less than -7.5 and -10 dBm (referenced at the receiver input terminals).

(d) The value of K_3/K_1 can be assumed essentially constant for the regions specified by (a), (b), and (c).

V ELT (EMERGENCY LOCATOR TRANSMITTER) MODEL

During the course of this investigation, it was found that a considerable interference problem was encountered on aircraft carrying certain ELT's. Substantial effort and time was expended investigating these effects and in the modeling of this device. The results of these investigations are documented in Appendix C.

VI APPLICATION

To illustrate the procedures involved in determining possible interference problems using the model proposed, consider the simple case where there exist only two interfering FM stations. The geometry of the problem is assumed to be that shown in Figure 5.

The analysis of the problem can be separated into three specific topics, i.e.,

(a) Calculation of signal strengths at the receiver input terminals.

(b) Calculation of "brute-force" interference contributions.

(c) Calculations of intermodulation distortion.

A. <u>Calculation of Signal Strengths</u>. The free space attenuation between lossless isotropic antennas is given by

$$\alpha\,(\mathrm{dB}) = 36.3 + 20 \log_{10} f + 20 \log_{10} d \qquad (12)$$

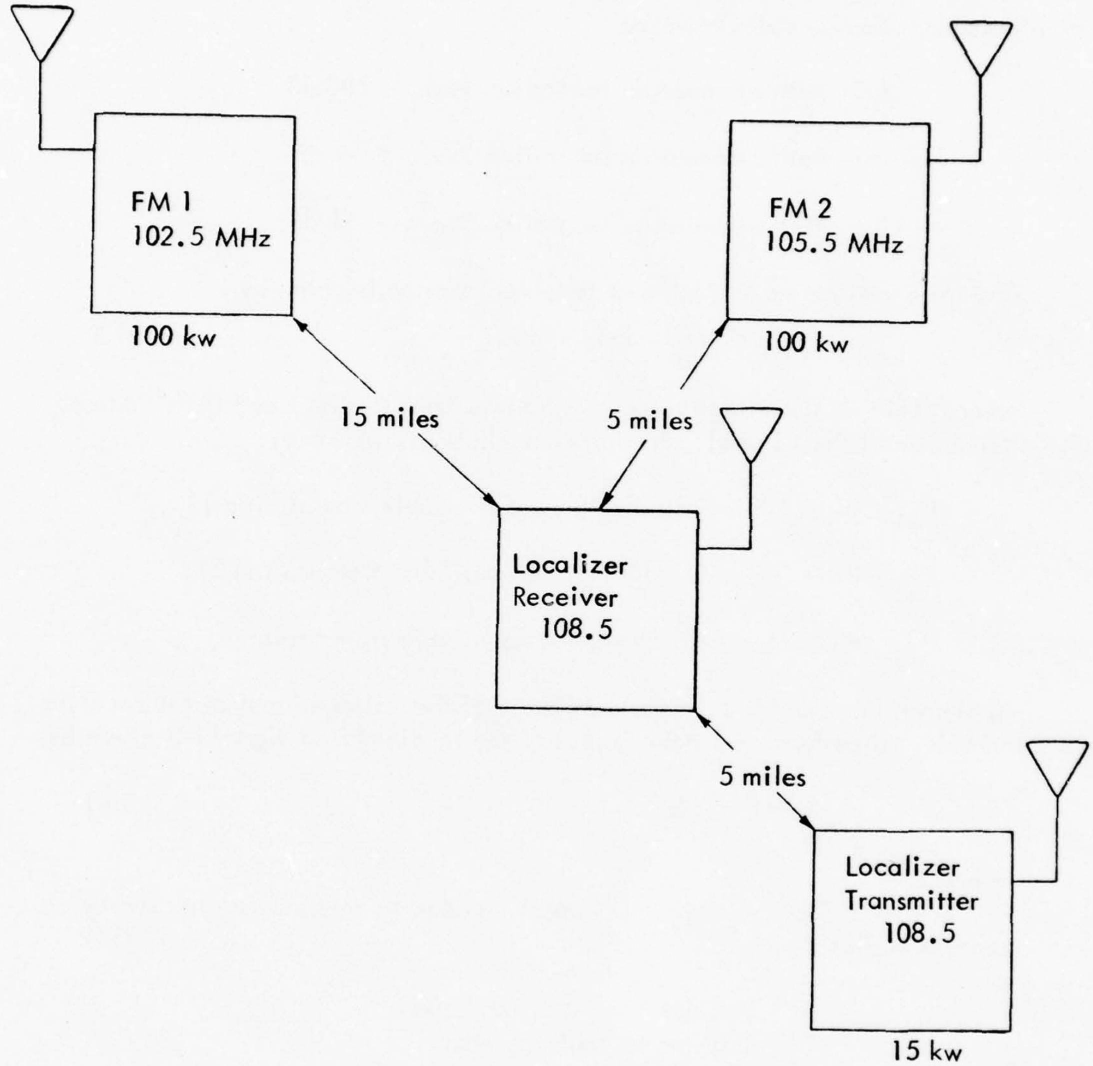


Figure 5. Typical Applications - An Example Interference Situation.

where f is the frequency in MHz and d is the distance in miles. Using (12) the path attenuations can be calculated as:

(a) Path attenuation for station 1: $\alpha_1 = 100$ dB

(b) Path attenuation for station 2: $\alpha_2 = 91$ dB

(c) Path attenuation for station 3: $\alpha_3 = 91$ dB

The maximum power available at receiver antenna is given by

$$P_{ai} = (ERP)_i - (Attenuation)_i \tag{13}$$

where $(ERP)_i$ is the effective radiated power from station 1 and $(Attenuation)_i$ is the attenuation of the i signal. For the example here, we have,

$P_{a1} = 80 - 100 = -20$ dBm (power available from station 1)

$P_{a2} = 80 - 91 = -11$ dBm (power available from station 2)

$P_{a3} = 42 - 91 = -49$ dBm (power available from station 3)

Applying the model requires a knowledge of the voltage input at the receiver input terminals. Therefore, the power input to the receiver from signal i is given by

$$P_i = P_{ai} - L_i \tag{14}$$

where

$L_i = A_i + C_i - D_i$ (total loss due to antenna cabling system on board the aircraft. (15)

A_i = loss due to aircraft antenna.
C_i = loss due to cabling, etc.
D_i = directive gain of antenna.

In general A_i and C_i would have to be estimated or measured for a particular application. For our example we use measured values obtained using a VOR/NAV antenna on a Cessna 150 aircraft, i.e.,

$$A_1 + C_1 = 9 \text{ dB} \quad (102.5 \text{ MHz}) \tag{16a}$$

$$A_2 + C_2 = 7 \text{ dB} \quad (105.5 \text{ MHz}) \tag{16b}$$

$$A_3 + C_3 = 3 \text{ dB} \quad (108.5 \text{ MHz}) \tag{16c}$$

The directive gain of the dipole antennas are assumed to be 6 dB; therefore, the signal levels at the input to the receiver are:

$$\text{FM1: } P_1 = -20 - 9 + 6 = -23 \text{ dBm} \tag{17a}$$

$$\text{FM2: } P_2 = -11 - 7 + 6 = -12 \text{ dBm} \tag{17b}$$

$$\text{Localizer : } P_3 = -49 - 3 + 6 = -46 \text{ dBm} \tag{17c}$$

With this information the next step is to calculate the effects of these signals in the receiver.

B. Calculation of Intermodulation Contribution. For the example here, assume the FM signal characteristics given below:

FM 1 (Signal B)	FM 2 (Signal C)
Tone modulation 10.42 KHz	Tone modulation 12.5 KHz
$\beta_1 = 2.4$ (Modulation Index)	$\beta_2 = 2.4$ (Modulation Index)

Mathematically the interfering signals can be described by either the time domain or frequency domain descriptions. For example for the B signal (FM 1) the expressions are:

$$e_b(t) = B \cos [\, b\,t + \beta_1 \sin \omega_1 t\,] \tag{18a}$$

$$\omega_1 = 2\pi\,(10{,}420)$$

$$e_b(t) = B \sum_{m=-N}^{N} J_m(\beta_1) \cos [b\,t + m\omega_1 t] \quad \text{(spectral representation of the FM signal)} \tag{18b}$$

After passing through the input filter the results are,

$$e_b'(t) = B \sum_{m=-N}^{N} \alpha(b + m\omega_1)\, J_m(\beta_1) \cos [b\,t + m\omega_1 t]$$

where N spectral components are assumed adequate for the representation and the input filter is assumed to have an attenuation of $\alpha(\omega)$ at frequency ω and no phase shift.

Similarily for FM 2:

$$e_c(t) = C \cos [\, c\,t + \beta_2 \sin \omega_2 t\,] \tag{19a}$$

where $\omega_2 = 2\pi\,(12{,}500)$

$$e_c'(t) = C \sum_{k=-M}^{M} \alpha(c + k\omega_2)\, J_k(\beta_2) \cos [c\,t + k\omega_2 t] \tag{19b}$$

Using the Table 1 the term of interest in this example is (the RF filter removes the rest of the terms):

$$3/4\ BC^2 \cos\left[(2c-b)t + 2\Phi_2 - \Phi_1\right] \tag{20}$$

$$(2c-b)/2\pi = 2\,(105.5) - 102.5 = 108.5\ \text{MHz}$$

Using (18b) and (19b) the intermodulation term in (20) can be written:

$$IM = (3/4)K_3\, BC^2 \sum_{m=-N}^{N} \sum_{k=-M}^{M} \sum_{l=-M}^{M} \alpha(b + m\omega_1)$$

$$\alpha(c + k\omega_2)\, \alpha(c + l\omega_2)\, J_k(\beta_2)\, J_l(\beta_2)\, J_m(\beta_1)$$

$$\cos\left[(2c-b)t + (k+l)\,\omega_2 t - m\omega_1 t\right] \tag{21a}$$

where K_3 is a parameter of the model and $\alpha(\omega)$ is the input filter attenuation. The IF frequency characteristics are assumed given by $\gamma(\omega)$; hence, the output of the IF is

$$IM = 3/4\ K_3 BC^2 \sum_{m=-N}^{N} \sum_{k=-M}^{M} \sum_{l=-M}^{M} \alpha(b + m\omega_1)\, \alpha(c + k\omega_2)$$

$$\alpha(c + l_2)\, \gamma\left[2c-b + (k+l)\,\omega_2 - m\omega_1\right] \tag{21b}$$

$$J_k(\beta_2)\, J_l(\beta_2)\, J_m(\beta_1) \cos\left[(2c-b)t + (k+l)\,\omega_2 t - m\omega_1 t\right]$$

In this equation the number of terms that must be considered in each summation depends on the modulation index and the AM detector output depends on the number of terms passed by the IF-amplifier, which depends on the bandwidth. The method used to specify the number of terms considered is the "rule of thumb" quite often used in practice to specify the bandwidth of an FM signal, i.e.,

$$\text{Bandwidth} = 2\, f_m\, (1 + \beta)$$

where f_m is the modulation frequency and β is the modulation index. The number of terms in the series expansion for the FM signal that must be considered is

$$\text{No. of terms} = 2\, fm\, (1 + \beta) / 2\, fm = 1 + \beta$$

In particular, for the case being considered, i.e., $\beta_1 = 2.4$, $f_1 = 10.42$ KHz $\beta_2 = 2.4$ and $f_2 = 12.5$ KHz, the number of terms that should be retained is

$$N = 3\text{–}4 \text{ and } M = 3\text{–}4$$

Further modifications of the spectral components will occur due to the RF and IF characteristics of the receiver.

The results given in (21a) can be simplified by assuming the input filter $\alpha(\omega)$ a constant. This will have very little effect on the results, since most of the AM distortion (due to FM-to-AM conversion) results from the bandlimiting through the IF-amplifier. With this assumption the squared term (e_c^2 (t)) can be written in the time domain as

$$e_c^2 (t) = C^2 \{ \cos [c\, t + \beta_2 \sin \omega_1 t] \}^2 \qquad (22)$$

$$e_c^2 (t) = C^2 / 2 \{ 1 + \cos [2\, c\, t + 2\, \beta_2 \sin \omega_1 t] \} \quad \alpha^2 (c)$$

where α (c) has been assumed constant over the bandwidth of the signal. The term in (22) which contributes to the intermodulation distortion is

$$(C^2 / 2) \cos [2\, c\, t + 2\, \beta_2 \sin \omega_2 t] \quad \alpha^2 (c) \qquad (23)$$

Note the term in (23) is simply an FM signal with a carrier frequency and modulation index twice that of the original waveform.

Using (23), the intermodulation components contained in the term

$3\, e_b\, e_c^2\, k_3$ are:

$$IM = \frac{3\, \alpha^2 (c)\, \alpha (b)\, k_3\, BC^2}{4} \sum_k \sum_m J_m (\beta_1)\, J_k (2\beta_2) \cos [(2\, c - b)\, t + k\omega_2 t - m\omega_1 t] \qquad (24)$$

Table 6 lists the coefficients of the FM signals e_b (t) and e_c^2 (t) which are above .01 *in magnitude for the specific case of* $\beta_1 = 2.4$, $f_1 = 10.42$ KHz, $\beta_2 = 2.4$ and $f_2 = 12.5$ KHz.

Table 7 lists the various intermodulation terms along with the components of the original FM signal which generates them. Only terms with amplitudes above .01 are listed to show how each term is generated.

For example, the first listing in Table 7 is generated from the interaction of 7th order term of the squared signal e_c^2 (t) and the 1st order term of the e_b (t), i.e.,

$k = -7$ of e_c^2 (t): $J_{-7} (2 \cdot 2.4) \cos \quad [2\, c\, t - 7 \cdot 2\pi\, (12,500)\, t]$;

$m = 1$ of e_b (t): $J_1 (2.4) \cos [b\, t + 2\pi\, (10,420)\, t]$

Amplitude of IM relative to unmodulated IM = (J_{-7} (4.8))

$J_{-7}(4.8) \cdot J_1(2.4) = (.0429)(.520) = .00223$

Spectral frequency = (-7) (12.5) - 10.42 = - 97.92 KHz

For this example, the signal levels are

B - signal power = -23 dBm

$B_{rms} = 15.8$ mv

C - signal power = - 12 dBm

$C_{rms} = 56.3$ mv

Order n	$J_n(\beta_1) = J_n(2.4)$ Amplitude Coeff. of $e_b(t)$	$J_n(2\beta_2) = J_n(4.8)$ Amplitude Coeff. of $e_c^2(t)$
0	0.00251	-0.24043
1	0.52019	- 0.29850
2	0.43098	0.11605
3	0.19811	0.39521
4	0.06431	0.37796
5	0.01624	0.23473
6	0.00337	0.11105
7	0.00059	0.04290
8	0.00009	0.01408

Table 6. Coefficients of the FM signals $e_b(t)$ and $e_c^2(t)$ for $\beta_1 = 2.4$, $f_1 = 10.42$ KHz, $\beta_2 = 2.4$ and $f_2 = 12.5$ KHz.

Considering the effects of the intermod only and assuming that the intermodulation center frequency is the same as the receiver frequency, i.e., 2 c-b = a, the effects can easily be evaluated. Combining (24) with the desired signal the output can be written

$$v_1(t) = A K_1 \cos a t + \frac{3}{4} a(b) a^2 (c) k_3 BC^2 \sum_k \sum_n J_n(B_1) \cdot$$

$$J_k(2\beta_2) \cos [a t + k \omega_2 t - m\omega_1 t] \qquad (25)$$

Output Intermod Freq. in KHz (Relative to Intermod. Center Frequency)	Output Intermod. Level (Relative to Unmodulated Intermod.)	Order of C^2 Used to Generate Intermod.	Order of B to Generate Intermod.
-97.92	-0.0223	-7	1
-85.42	0.0578	-6	1
-95.84	0.0479	-6	2
-72.92	-0.1221	-5	1
-83.34	-0.1012	-5	2
-93.76	-0.0465	-5	3
-60.42	0.1966	-4	1
-70.84	0.1629	-4	2
-81.26	0.0749	-4	3
-91.68	0.0243	-4	4
-47.92	-0.2056	-3	1
-58.34	-0.1703	-3	2
-68.76	-0.0783	-3	3
-79.18	-0.0254	-3	4
-35.42	0.0604	-2	1
-45.84	0.0500	-2	2
-56.26	0.0230	-2	3
-22.92	0.1553	-1	1
-33.34	0.1286	-1	2
-43.76	0.0591	-1	3
-54.18	0.0192	-1	4
-10.42	-0.1251	0	1
-20.84	-0.1036	0	2
-31.26	-0.0476	0	3
-41.68	-0.0155	0	4
2.08	-0.1553	1	1
-8.34	-0.1286	1	2
-18.76	-0.0591	1	3
-29.18	-0.0192	1	4
14.58	0.0604	2	1
4.16	0.0500	2	2
-6.26	0.0230	2	3

Table 7. IM Spectrum.

Output Intermod. Freq. in KHz (Relative to Intermod. Center Frequency)	Output Intermod. Level (Relative to Unmodulated Intermod.)	Order of C^2 Used to Generate Intermod.	Order of B to Generate Intermod.
27.08	0.2056	3	1
16.66	0.1703	3	2
6.24	0.0783	3	3
-4.18	0.0254	3	4
39.58	0.1966	4	1
29.16	0.1629	4	2
18.74	0.0749	4	3
8.32	0.0243	4	4
52.08	0.1221	5	1
41.66	0.1012	5	2
31.24	0.0465	5	3
20.82	0.0151	5	4
64.58	0.0578	6	1
54.16	0.0479	6	2
43.74	0.0220	6	3
77.08	0.0223	7	1
66.66	0.0185	7	2

Table 7. IM Spectrum (Continued).

This signal is further filtered by the output stage of the RF-amplifier and the IF-amplifier stages. For simplicity assume the filtering due to the IF to be ideal with characteristics shown in Figure 6.

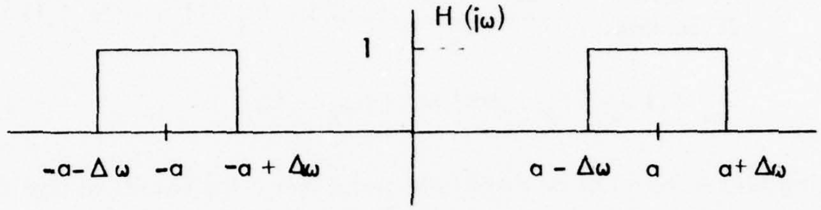


Figure 6. IF Characteristics.

The IF-bandwidth is assumed to be 50 KHz i.e., $\Delta\omega = (2\pi) \cdot (25) \cdot (10^3)$. With this assumption only those components within 25 KHz of the carrier will be passed by the IF-amplifier. These are listed in Table 8.

IM Component Frequency Relative to Carrier	Amplitude Relative to Unmodulated IM
2.08	0.16
4.16	.05
4.18	.03
6.24	.08
6.26	.02
8.32	.02
8.34	.13
10.42	.13
14.58	.06
16.66	.17
18.74	.07
18.76	.06
20.82	.02
20.84	.10
22.92	.16

Table 8. IM Components Out of IF. Only Those Components Above the Carrier Frequency are Listed. Those Below are the Same.

The effects of the IF-amplifier are represented by selecting the terms in the summation given in (25) which are within the receiver bandwidth, i.e.,

$$v_2(t) = K_1 A \cos a t + \text{Terms in IF Bandpass} \left\{ \frac{3 BC^2 K_3 \alpha(b) \alpha^2(c)}{4} \sum_{k=-(\beta_1+1)}^{\beta_1+1} \sum_{n=-(2\beta_2+1)}^{2\beta_2+1} \right.$$

$$\left. J_m(\beta_1) J_k(2\beta_2) \right\} \cos\left[a t + n\omega_2 t - k\omega_1 t \right] \qquad (26)$$

Rewriting (26) in terms of an amplitude and a phase the results of passing this signal through an envelope detector can easily be determined, i.e.,

$$K_1 A \left[1 + d_1(t) K_3 / A K_1 \right]$$

where $d_1(t) = \underset{\text{IF passband}}{\text{Terms within}} \left\{ (3/4\alpha(b)\alpha^2(c)\; B C^2 \sum_k \sum_n J_n(\beta_1) \right.$

$$\left. J_k(2\beta_2) \cos\left[(k\omega_2 - n\omega_1) t \right] \right\} \qquad (27)$$

For the example being illustrated here we have the following:

$\alpha(b) = \alpha(102.5) = -9$ dB (.36 linear magnitude)
$\alpha(c) = \alpha(105.5) = -4.5$ dB (.6 linear magnitude)

$A_{rms} = 1.123$ m volts

$$\text{Max} \left| d_1(t) \right| = \frac{3\, BC^2}{4} \alpha(b)\, \alpha^2(c)\, F = 2\sqrt{2}\,(4.87 \times 10^{-6})\, F$$

where F is a factor introduced that accounts for the IF filtering and the phase differences between the spectral components. The maximum value of the ratio $d_1(t)/A$ is,

$$\text{Max} \left| \frac{K_3 d_1(t)}{K_1 A} \right| = 20\,(8.67 \times 10^{-3} F) = .173F$$

where $K_3/K_1 = 20$ (linear). This value would indicate a significant interference potential.

This model can be used in several other ways. For example, the following question might be asked: What minimum distance must be maintained between the localizer receiver and two 100 kw FM stations, operating at frequencies such that an intermod at the localizer frequency is produced, to avoid IM distortion. The distortion criteria is based arbitrarily on the following:

$$\text{If Max} \left| (d_1 (t) / A) \frac{K_3}{K_1} F \right| > .1 \text{ distortion potential}$$

$$\text{If Max} \left| (d_1 (t) / A) \frac{K_3}{K_1} F \right| < .1 \text{ no distortion}$$

The arbitrary decision criterion listed above assumes that the receiver would capture the stronger localizer signal; however, there would be notable output when there is no desired signal present at interference signal levels below these values.

Note here we have arbitrarily taken the Max$\{ d_1 (t) K_3 F/A K_1 \}$ as the statistic. Whether or not this is a good statistic needs further investigation.

For the example calculation we have

$$\text{Max} \left| \frac{d_1 (t) K_3}{A K_1} \right| = \frac{3 BC^2 F K_3 \alpha(b) \alpha^2 (c)}{4 A K_1}$$

(B and C are peak values). If a decision boundary of 0.1 is used and the specific values for this example are used the equality in (28) holds.

$$B \text{ (dBM)} < -2 \text{ C (dBm)} + \text{A (dBm)} - 20 \log F - 20 \log K_3/K_1 - 5.5 \qquad (28)$$

We have used the attenuations α (c) = -4.5 dB and α(b) = -9 dB.

The region of allowable combinations of signal levels B and C which would pose no interference potential under our criterion is illustrated in Figure 7.

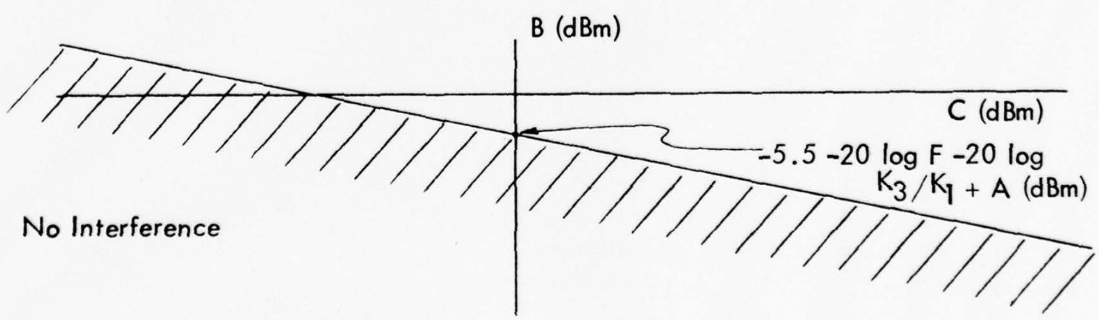


Figure 7. Signal Levels for No Interference.

The developed equations can be combined to place restrictions on the minimum allowable distance from the localizer receiver for the commercial FM antenna. The power input to the receiver in dBm (assuming $(ERP)_i$ expressed in dBm) is

$$P_i = (ERP)_i - 36.3 - 20 \log_{10} f - 20 \log_{10} d - L_i \qquad (29)$$

Using this relation the signal level in dBm available at the input to the receiver is (using the B signal as example)

$$B\ (dBm) = (ERP)_B - 36.3 - 20 \log_{10} b - 20 \log_{10} d_b - L_b \qquad (30)$$

Putting in the specific values for this example the result is

$$-20 \log d_B < -42.4 - K_3/K_1\ (dB) - 20 \log d_a + 40 \log d_c \qquad (31)$$

The value of $3\,K_3/2K_1$ has been given in the previous section for the NAV 11 receiver as approximately 4 dB; hence $K_3/K_1 = .5$ dB. Assuming F = I, (31) becomes,

$$20 \log d_b > 42.9 + 20 \log d_a/d_c^2 \text{ or } d_b\, d_c^2 > 140\, d_a \qquad (32)$$

Assuming a critical distance of 5 miles from the localizer (32) indicates there would be a potential interference if the distances are such that

$$d_b\, d_c^2 > 698 \qquad (33)$$

Using (33) the regions of interference can be identified as illustrated in Figure 8.

d_c	d_b	d_a
26	1	5
18.7	2	5
15.2	3	5
13.2	4	5
11.8	5	5
8.3	10	5
5.9	20	5

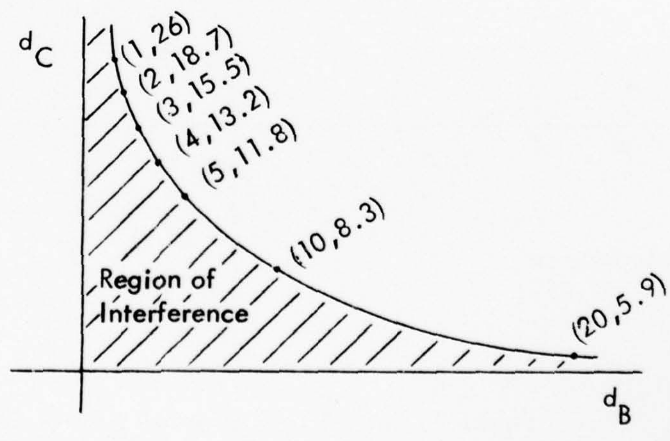


Figure 8. Regions of Interference.

Assuming F to be unity gives a pessimistic result in general. Another statistic which has been used is the RMS output of the detector which is very simple to calculate and measure. Experimental and theoretical results using this as the statistic have been shown to agree very well and since it is easier to specify, is probably the better statistic. Using the RMS value at the output of the detector we define the modulation factor (MF) as,

$$MF = \frac{\text{RMS Detector Output with FM Modulated Signal}}{\text{RMS Detector Output with FM Carrier Only}} \quad (34)$$

Experimental and analytical results obtained are given in Table 9.* In order to obtain the experimental results a true RMS reading meter and a full wave rectifying averaging AC digital voltmeter were used to measure the detector output. It is seen that the experimental and calculated results agree very well.

C. Cross-Modulation Considerations. As indicated earlier, the terms contributing to cross-modulation effects result from:

(1) e_a^3 (generally small, so this term can be neglected)

(2) $3e_a e_b^2$ and $3e_a e_c^2$

It is easy to show that there would be no cross-modulation distortion produced other than a change in carrier level if all frequency components are passed with the same attenuation α. Since the frequencies of the interfering FM stations are located in the "skirts" of the localizer receiver characteristics, each frequency component will be attenuated differently. The different attenuation of each of the frequency components results in AM modulation which appears as cross-modulation on the localizer signal.

To account for these effects, it is necessary to have available the receiver selectivity characteristics. A very simple compact expression can be used to calculate these effects. Considering one interfering signal, i.e.,

$$e_b(t) = B \cos [bt + \beta_1 \sin \omega m_1 t]$$

The equivalent Fourier series representation is

$$e_b(t) = B \sum_{m=-\infty}^{\infty} J_m(\beta_1) \cos [bt + m\omega_1 t] \quad (35)$$

Assuming the "skirt" characteristics of the input filter of the RF-amplifier can be approximated by a linear amplitude-frequency characteristic and zero phase shift as

---

* Details of the measurement procedures and results are given in Appendix D.

105.500 MHz Modulating Frequency	Beta	102.500 MHz Modulating Frequency	Beta	MODULATION FACTOR Measured With DVM Meter	Measured With RMS Meter	Calculated with Program Using Triangular Filter Function
12.5 KHZ	2.40	10.42 KHz	2.40	.255	.27	.262
9.06 KHz	5.52	5.43 KHz	5.52	.203	.245	.211
3.12 KHz	2.40	4.16 KHz	2.40	.506	.598	.579
10.0 KHz	.631	9.43 KHz	.631	.738	.807	.746
.906 KHZ	55.2	.543 KHz	55.2	.118	.213	.206
None	0.0 No Modulating	10 KHz	.631	.633	.653	.927

Table 9. Summary of Measured and Calculated Results.

shown in Figure 9, the attenuation characteristics can be written

$$\alpha(b + k\omega_1) = \alpha(b) \mid 1 + k\omega_1 \delta \mid \qquad (36)$$

where $\delta = (\alpha(b + \Delta\omega) - \alpha(b))/\Delta\omega$

and is the slope of the input filter characteristics. Assuming an FM signal input to a filter such as described above, the output can be shown to be

$$v_o = \alpha(b)\,(1 + \beta\delta\omega_1 \cos\omega_1 t)\, B \cos(bt + \beta \sin\omega_1 t) \qquad (37)$$

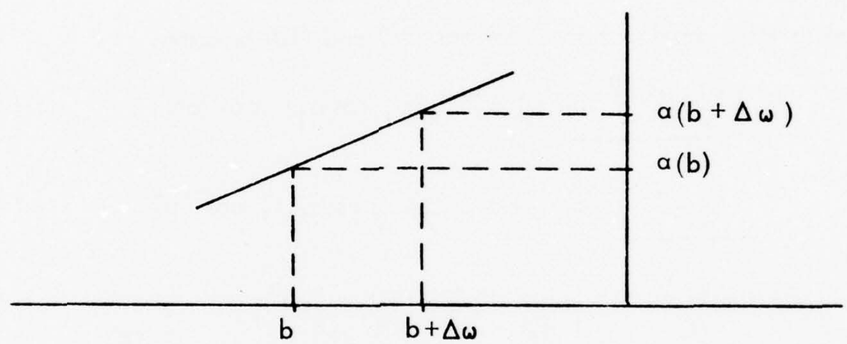


Figure 9. "Skirt" Characteristics.

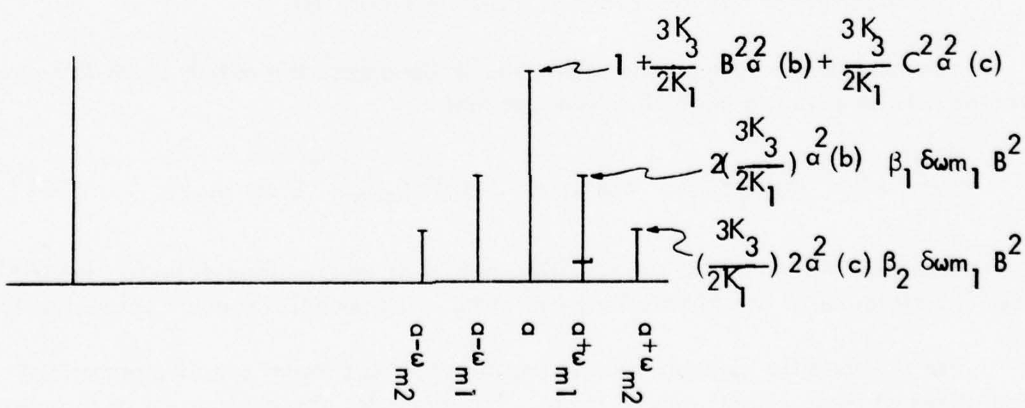


Figure 10. Signal Spectrum.

It is seen that the frequency modulation of the output is the same as the input, but in addition there is amplitude modulation which is the same as the original modulating signal. The percent AM modulation produced by this attenuation function is

$$\% \text{ modulation} = \beta\delta\,\omega_1 \times 100 \qquad (38)$$

The cross-modulation effects are given by

$$\frac{3\,AB^2\,\alpha^2(b)}{2}\left[1 + \beta_1\,\delta'\omega_1 \cos\omega_1 t\right]^2 \cos(at) \qquad (39)$$

and

$$\frac{3\,AC^2}{2}\,\alpha^2(c)\left[1+\beta_2\,\delta''\omega_2 \cos\omega_2 t\right]^2 \cos(at) \qquad (40)$$

Assuming $\beta\ \delta$ small, then equations (39) and (40) become,

$$\frac{3\,K_3AB^2\,\alpha^2(b)}{2}\left[1 + 2\,\beta_1\delta'\omega_1 \cos\omega_1 t\right] \cos(at) \qquad (41)$$

and

$$\frac{3\,K_3AC^2\,\alpha^2(c)}{2}\left[1 + 2\,\beta_2\delta''\omega_2 \cos\omega_2 t\right] \cos(at) \qquad (42)$$

Combining these with the desired signal the result is

$$e_o = K_1A\left\{1 + \frac{3K_3}{2K_1}B^2\alpha^2(b) + \frac{3K_3}{K_1}C^2\alpha^2(c) + \frac{3K_3}{2K_1}\right.$$

$$\left.\alpha^2(b)\,2\beta_1\delta'\omega_1\,B^2\cos\omega_1 t + \frac{3K_3}{2K_1}\alpha^2(c)\,2\beta_2\,\delta''\omega_2\,C^2\cos\omega_2 t\right\}\cos at \qquad (43)$$

The spectrum of this wave form is shown in Figure 10.

Assuming these components within the IF Bandpass, the output of an AM envelope detector will be within a multiplicative constant

$$\frac{3K_3}{2K_1}\left[2\,\alpha^2(b)\,\beta_1\delta\omega_1\,B^2\cos\omega_1 t + 2\,\alpha(c)^2\,\beta_2\omega_2\,C^2\delta''\cos\omega_2 t\right] \qquad (44)$$

Equation (44) specifies the resulting output of an envelope detector due to "brute-force" interference of two FM stations operating at frequencies b and c respectively.

For the specific example being considered in this report specific numerical calculations of these effects can be made. For example, the peak value of the percent AM modulation due to the interfering stations can be calculated, i.e.,

$$\% \text{ AM-Mod}_{\text{peak}} = \frac{\frac{3}{2}\frac{K_3}{K_1} \mid 2\alpha^2 (b)\, \beta_1 \delta' \omega_1\, B^2 + 2\alpha^2 (c) \beta_2\, C^2 \delta'' \omega_2 \mid}{1 + \frac{3K_3}{2K_1} \mid B^2 \alpha^2 (b) + C^2 \alpha^2 (c) \mid} \times 100 \qquad (45)$$

For the example being considered,

$\alpha (b = 102.5) = -9$ dB (.355 linear)

$\alpha (c = 105.5) = -4.5$ dB (.6 linear)

$$\frac{3K_3}{2K_1} = 31.7 \text{ linear}$$

$$\beta_1 = \beta_2 = 2.4$$

$$\omega_1 = (2\pi)\ (12{,}500)$$

$$\omega_2 = (2\pi)\ (10{,}420)$$

$$\delta' = \frac{.0612}{1 \text{ MHz}}, \quad \delta'' = \frac{.103}{1 \text{ MHz}} \quad \text{(see Figure H-2)}$$

B = -23 dBm; B = 15.8 mv (RMS)

C = -11 dBm; C = 56.3 mv (RMS)

Using these (45) gives the percent AM modulation due to "brute-force" interference as

% AM modulation = .04%

The above percent AM modulation due to "brute-force" interference seems minimal when compared with that due to intermodulation as given in the previous section. This, of course, is due to frequencies being chosen so as to produce an intermod at the frequency the receiver is tuned to and having the modulation indices low.

D. Combined Effects of Intermod and "Brute-Force" Interference. Although calculations for the example given here indicate that the "brute-force" interference is minimal when compared with the intermod, it is desirable to indicate how these two effects can be combined.

The RF output resulting from the desired signal and an intermod is

$$K_1 A \cos at + d_1 (t) \cos (at + \Phi) + d_2 (t) \sin (at + \Phi) \qquad (46)$$

where it has been assumed that 2 c−b = a . If this is not the case, then the proper frequency will have to be specified in the last two terms of (46). Using (43) and (46) the combined effects are given by

$$\text{Distortion} = K_1 A \; [\, 1 + \frac{3K_3}{2K_1} B^2 \alpha^2 (b) + \frac{3K_3}{2K_1} C^2 \alpha^2 (c) +$$

$$\frac{3K_3}{2K_1} 2 \alpha^2 (b)\, \beta_1\, \delta'\omega_1\, B^2 \cos \omega_1 t + \frac{3K_3}{2K_1} 2 \alpha^2 (c)\, \beta_2\, \delta''\omega_2\, C^2 \cos \omega_2 t +$$

$$\frac{K_3}{K_1 A} d_1 (t) \cos at + \frac{K_3}{K_1 A} d_2 (t) \sin at \qquad (47)$$

Equation (47) has made some simplifying assumptions which could be considered worst case. For example, it has been assumed that all components are in phase, which is not true in general. This assumption will provide a worst case analysis; however, the technique can be extended to account for different phases.

The output of an envelope detector would be (using (47)).

$$K_1 A \, \{ 1 + \frac{K_3}{K_1} (\tfrac{3}{2} B^2 \alpha^2 (b) + \tfrac{3}{2} C^2 \alpha^2 (c) + \tfrac{3}{2} 2\alpha^2 (b)\, \beta_1\, \delta'\omega_1\, B^2$$

$$\cos \omega_1 t + \tfrac{3}{2}\, 2\alpha^2 (c)\, \beta_2\, \delta''\omega_2\, C^2 \cos \omega_2 + \frac{d_1 (t)}{A})^2 + \frac{K_3^{\,2}}{K_1^{\,2} A^2} d_2^{\,2} (t) \, \}^{1/2}$$

$$(48)$$

This expression can be approximated by

$$K_1 A \;\; \{ 1 + \frac{3K_3}{2K_1} B^2 \alpha^2 (b) + \frac{3}{2} \frac{K_3}{K_1} C^2 \alpha^2 (c)$$

Carrier compression term due to "brute-force"

$$+ \frac{3}{2} \frac{K_3}{K_1} [\, 2\, \alpha^2 (b)\, \beta_1 \delta'\omega_1\, B^2 \cos \omega_1 + 2\, \alpha^2 (c)\, \beta_2\, \delta''\omega_2\, C^2 \cos \omega_2 t \,] \quad + \frac{d_1 (t)}{A} \, \} \qquad (49)$$

AM-modulation term due to "brute-force" interference (cross-modulation)

Intermod Term

In obtaining (49) the squared terms have been neglected. It has been assumed that

$$\frac{K_3^{\,2}}{K_1^{\,2} A} \quad d_2^{\,2}(t) \ll 1$$

and

$$\left(\frac{K_3}{K_1}\right)^2 \left(\frac{3}{2} B^2 \alpha^2 (b) + \frac{3}{2} B^2\, 2\, \alpha^2 (b)\, \beta_1 \delta' \omega_1 \beta^2 \cos \omega_1 t + \frac{3}{2}\, 2\, \alpha^2 (c)\right.$$

$$\left. \beta_2 \delta'' \omega_2 C^2 \cos \omega_2 t + \frac{d_1(t)}{A} \right)^2 \ll 1$$

These conditions hold except in cases of extreme interference.

VII EXTENSIONS OF THE TECHNIQUES

The extensions of the techniques to handle cases where there are multiple interfering sources are conceptually very simple; however, the calculations required would be lengthy and involved. A computer program was written which would perform the required computation for any specified number of interfering stations. As an example we evaluate the interference potentials in the greater Birmingham, Alabama area airport. This region was chosen due to the fact that there have been reported cases of interference with airborne communications and navigational receivers.

Figure 11 shows the area of interest and Figure 12 shows an expanded view of the area along with the various FM broadcast stations of interest.

Table 10 lists the various FM broadcast station call letters, frequencies, coordinates and powers and Table 11 lists the localizer frequency (110.3 MHz) and its coordinates, along with the outer marker location and the VOR frequency and location.

Using the data the approximate distances of each FM station from the localizer are given in Table 12.

Table 13 gives a listing of the various signal levels at the receiver assuming a normalized distance of 1 mile from each radiating source and the receiver. In order to apply the tabulated results they must be adjusted by a correction factor which would account for the proper distance from the FM source to the receiver. This correction factor is 20 $\log_{10} d$, where d is in miles.

Assuming a localizer power of 40 watts and a normalized distance of one mile from the receiver the following results for the localizer are obtained:

Frequency = 110.3 MHz
Miles from localizer = 1 mile
Free space attenuation = 77.2 dB

1 Nautical Mile = 1.15 Statute Miles

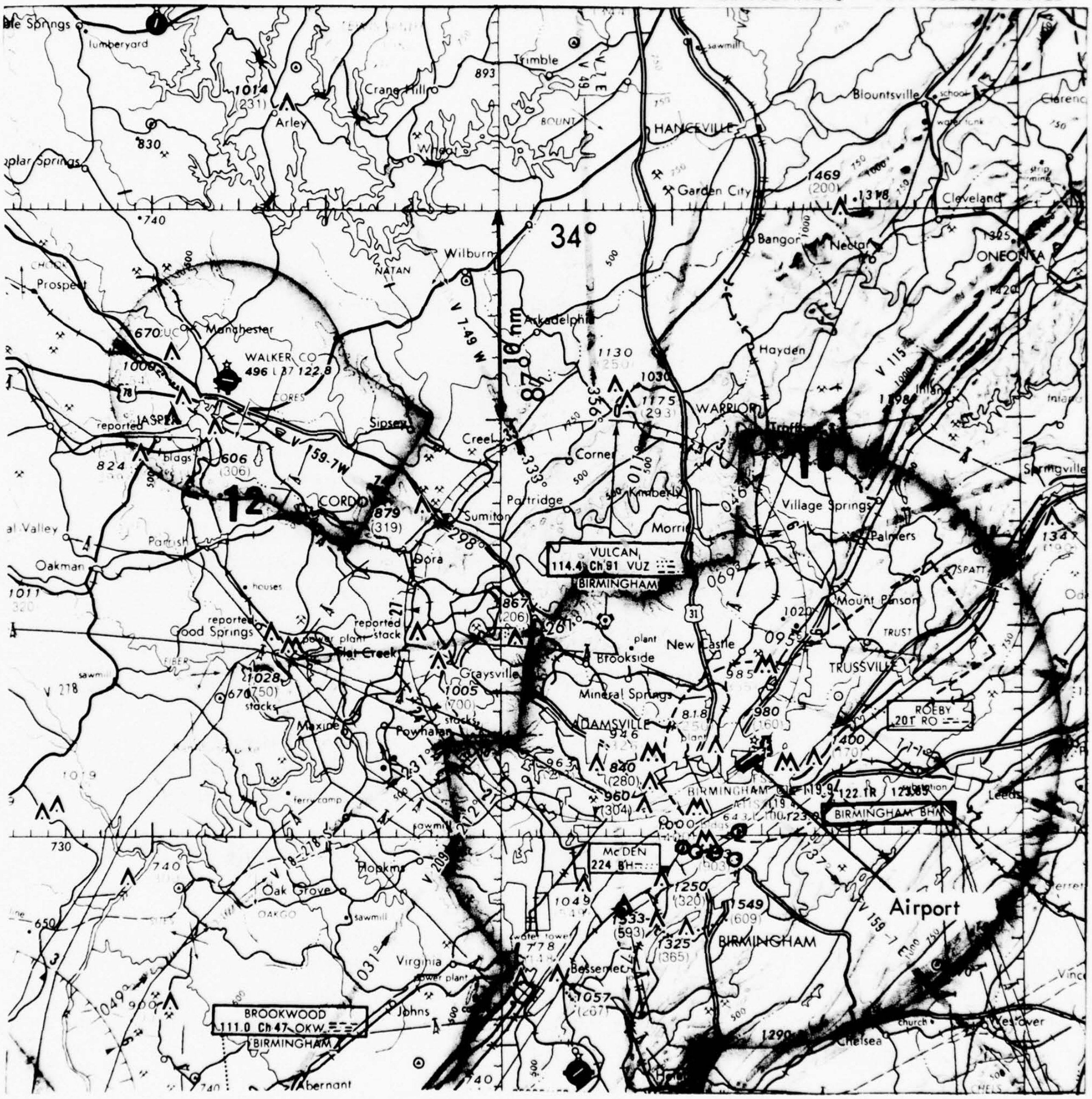


Figure 11. Birmingham, Alabama Airport Area.

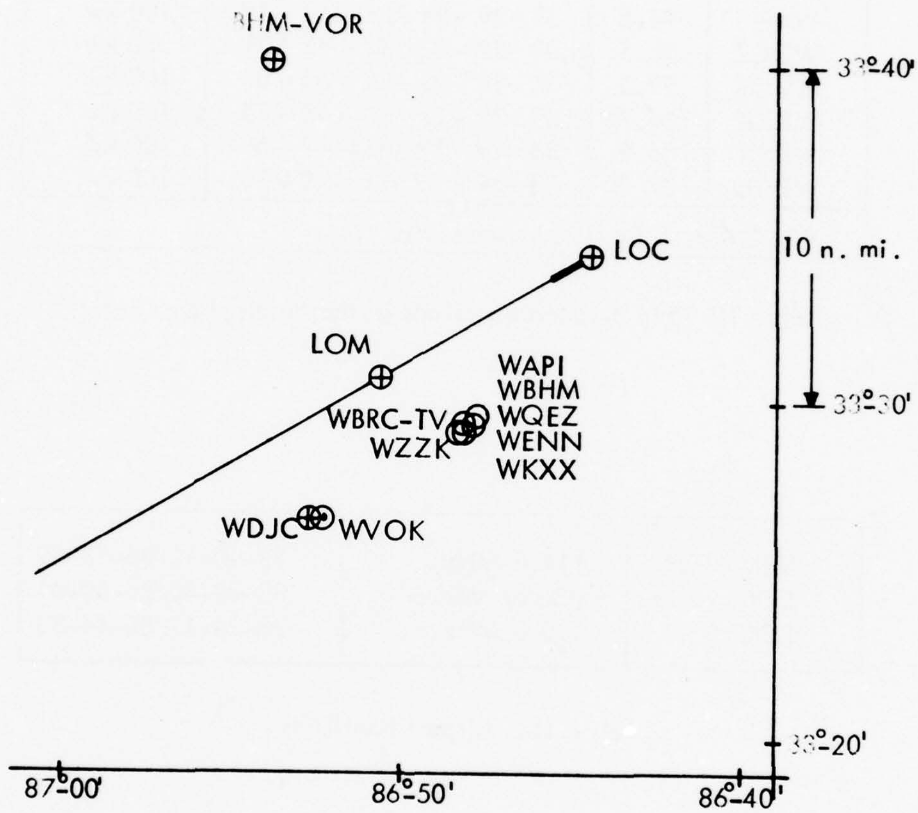


Figure 12. Location of FM Broadcast Stations in Birmingham Area.

Call Letters	Freq. In MHz.	Coordinates	Power
WBHM	90.3	33°-29'-19"/86°-47"-58"	50 kw
WDJC	93.7	33 - 26 -36 /86 - 52 - 50	100 kw
WAPI	94.5	33 -29 - 26 /86 - 47 - 48	100 kw
WQCZ	96.5	33 -29 - 02 /86 - 48 - 21	50 kw
WVOK	99.5	33 -26 - 28 /86 - 55 - 00	100 kw
WZZK	104.7	33 -29 - 02 /86 - 48 - 35	100 kw
WKXX	106.9	33 -29 - 19 /86 - 47 - 58	100 kw
WENN	107.7	33 -29 - 02 /86 - 48 - 35	100 kw
WBRC CH. 6 TV-100 kw also near			

Table 10. FM Broadcast Stations in the Birmingham Area.

BHM-VOR	114.4 MHz.	33-40-12/86-53-59
LOM	(Outer Marker)	33-30-40/86-50-44
LOC	110.3 MHz.	33-34-17/86-44-33

Table 11. Airport Facilities.

Station	Distance in miles
WBHM	6.1
WDJC	11.8
WAPI	5.9
WQCZ	6.4
WVOK	12.0
WZZK	6.6
WKXX	6.0
WENN	6.6

Table 12. Distance of FM Broadcast Stations from Localizer.

Station Freq. in MHz.	Distance from Station in Miles	Power of Station in dBm	Free Space Attenuation (6dB added directive gain of Nav antenna)	Attenuation loss (1 dB/ MHz below 108.5)	RF Filter Attenuation	Resultant Level in dBm at RF Amplifier input (assumes normal-ized Distance of 1 mile)
90.3	1.0	77.0	75.4	18.2	21.0	-31.6
93.7	1.0	80.0	75.7	14.8	18.4	-23.0
94.5	1.0	80.0	75.8	14.0	17.8	-21.7
96.5	1.0	77.0	76.0	12.0	16.3	-21.4
99.5	1.0	80.0	76.3	9.0	14.1	-13.4
104.7	1.0	80.0	76.7	3.8	8.4	-2.9
106.9	1.0	80.0	76.9	1.6	5.1	2.4
107.7	1.0	80.0	76.9	0.8	3.9	4.4

Receiver Frequency is 110.30, Receiver Bandwidth is 40.0 KHz. Frequencies which produce intermod interference are:

FI	F2	F3	IM Type	IM Center Freq.
93.7	106.9	90.3	F1+F2-F3	110.30

IM level, no modulation
43.2 dBm*

* This assumes a distance of 1 mile from each station, 3/2 $K_3/K_1 = 3$ dB.

Table 13. Printout of Signal Level Computations.

Power in dBm = 46.
Antenna loss = 0
Input Filter loss = 0

Resultant desired signal level at RF amplifier input = -25.1 dBm. This value must also be corrected for the distance.

Several calculations were made to investigate the interference problems relating to this area and are given below

(a) Receiver at location (1) in Figure 13

Referring to Figure 13 this calculation assumes the aircraft at position (1) closest distance to the cluster of FM stations.

Table 14 gives a computer printout of the signal level computations for each station and the various attenuation factors. Also included in Table 14 is the calculation of the localizer signal level at position (1). The predominant type of interference expected in this case is of the "brute-force" type as indicated by the signal levels in Table 14. Table 15 gives the cross-modulation resulting from each interfering station and also the resultant cross-modulation due to the combined effects of the interfering stations. For these computations a frequency deviation of 40 KHz was used and the slope characteristics of the receiver front-end (RF amplifier) were modeled by the following:

$$\delta = \begin{cases} .15 \text{ dB/100 KHz for frequencies less than 8 MHz away from the receiver frequency} \\ .075 \text{ dB/100 KHz outside the range} \end{cases}$$

Using this data the resultant AM modulation due to cross-modulation of the interfering signals was computed using the techniques given, which have been expanded to include more than two stations. The results of these calculations are given in Table 15.

For these calculations no modulation was assumed so that the maximum interference power is at the desired localizer frequency.

The statement at the bottom of Table 15 indicates that there is significant "brute-force" interference in this case. As a matter of fact, for this location the amount of cross-modulation calculated which results in compression of the desired signal is in excess of 1; hence, the third-order model would not be valid. However, this is of no consequence since there will definitely be high interference levels observed at this location.

Table 16 gives the resulting intermodulation results due to the interfering signals. It does not consider the effects of cross-compression. In any case the significant interference at this point is due to "brute-force" interference; however, the resulting compression of the desired signal would allow the relative weak intermod component to feed through and cause problems.

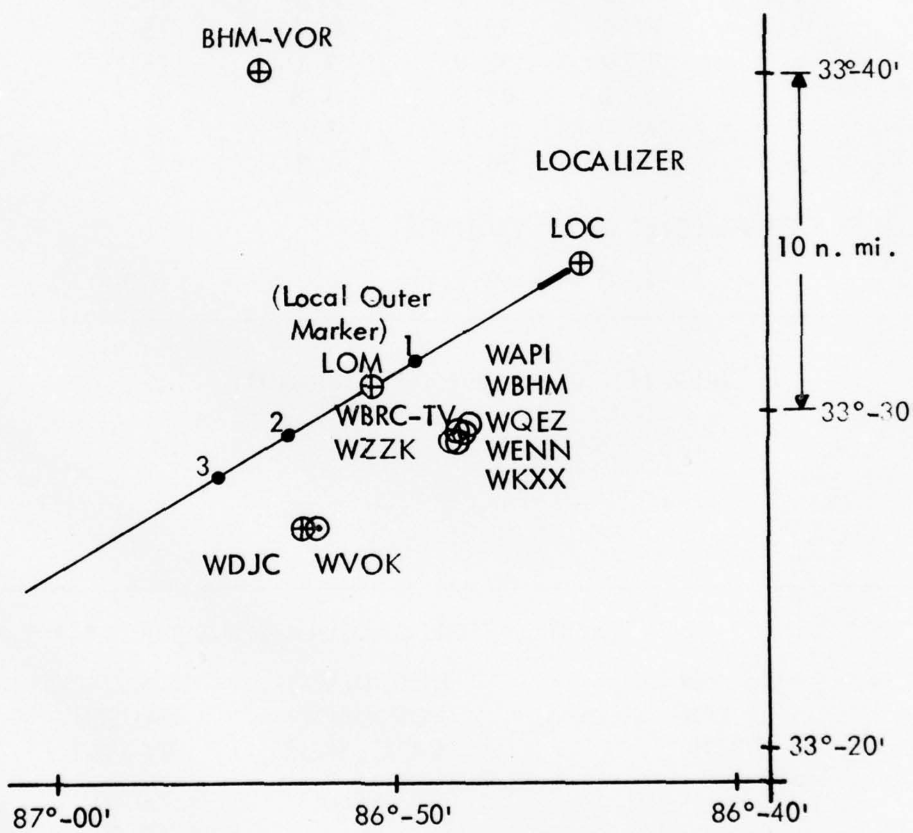


Figure 13. Map Showing Locations of FM Stations and Locations at Which the FM Station Interference is Analyzed.

PRINTOUT OF SIGNAL LEVEL COMPUTATIONS

STATION FREQ (MHZ)	MILES FROM RECEIVER	STATION POWER IN DBM	FREE SPACE ATTEN-DB	NAV ANTENNA LOSS-DB	RCVR INPUT FILTER ATTEN DB	SIGNAL LEV AT RFAMP IN DBM
90.3	2.9	77.0	84.7	18.2	19.2	-40.9
93.7	6.9	80.0	92.5	14.8	17.2	-39.8
94.5	2.9	80.0	85.1	14.0	16.7	-30.9
96.5	2.9	77.0	85.2	12.0	15.5	-30.6
99.5	6.9	80.0	93.0	9.0	13.7	-30.1
104.7	2.9	80.0	85.9	3.8	6.7	-12.1
106.9	2.9	80.0	86.1	1.6	4.1	-6.8
107.7	2.9	80.0	86.2	0.8	3.1	-4.9

LOCALIZER SIGNAL LEVEL CALCULATIONS:

110.3	6.7	46.0	93.7	0.0	0.0	-41.7

Table 14. Signal Levels at Location (1).

* * * * * * * * * * *CROSS MODULATION CALCULATIONS * * * * * * * * * * *

STATION FREQ (MHZ)	COMPRESSION OF LOC. SIGNAL IN DB	FREQ DEV. FOR XMOD CALC. (KHZ)	% AMMOD CAUSED BY STAT.
90.3	-0.0	40.	0.00
93.7	-0.0	40.	0.00
94.5	-0.0	40.	0.00
96.5	-0.0	40.	0.00
99.5	-0.0	40.	0.00
104.7	-1.6	40.	.11
106.9	-7.6	40.	1.08
107.7	-21.3	40.	9.33

****CROSS COMPRESSION GREATER THAN 1, THIRD ORDER MODEL OF RECEIVER NO LONGER VALID. TOTAL PERCENT MOD., NOT CONSIDERING CROSSCOMPRESSION= .86 COMPRESSION FACTOR 1.679 DESIRED SIGNAL COMPRESSION IN DB*****
TOTAL PERCENT AM MODULATION = *****

Table 15. Cross-Modulation Due to Interfering Signals. Receiver at Point (1) Location.

RECEIVER FREQUENCY IS 110.30 RECEIVER BANDWIDTH IS 40.0 KHZ

FREQUENCIES WHICH PRODUCE INTERMOD INTERFERENCE ARE:

F1	F2	F3	IM TYPE	IM CENTER FREQ
93.7	106.9	90.3	F1 + F2 - F3	110.30

IM LEVEL IN DBM, NO FM STAT. MODULATION

-81.5

Table 16. Intermodulation Interference. Receiver at Point (1) location.

PRINTOUT OF SIGNAL LEVEL COMPUTATIONS

STATION FREQ (MHZ)	MILES FROM RECEIVER	STATION POWER IN DBM	FREE SPACE ATTEN-DB	NAV ANTENNA LOSS-DB	RCVR INPUT FILTER ATTEN DB	SIGNAL LEV AT RFAMP IN DBM
90.3	3.5	77.0	86.3	18.2	21.0	-42.5
93.7	5.5	80.0	90.5	14.8	18.4	-37.8
94.5	3.5	80.0	86.7	14.0	17.8	-32.5
96.5	3.5	77.0	86.9	12.0	16.3	-32.2
99.5	5.5	80.0	91.1	9.0	14.1	-28.2
104.7	3.5	80.0	87.6	3.8	8.4	-13.8
106.9	3.5	80.0	87.8	1.6	5.1	-8.5
107.7	3.5	80.0	87.8	0.8	3.9	-6.5
LOCALIZER SIGNAL LEVEL CALCULATIONS:						
110.3	8.5	46.0	95.7	0.0	0.0	-43.7

Table 17. Signal Levels at LOM Location.

(b) Receiver at the LOM

Similar results are given assuming the aircraft at the Localizer Outer Marker (LOM) as noted in Figure 13. Tables 17, 18 and 19 give these results. Again it is observed that a significant interference due to "brute-force" is expected.

(c) Receiver at Point 2 on Figure 13

Tables 20, 21 and 22 give results when the aircraft receiver is at location 2.

****************CROSS MODULATION CALCULATIONS****************

STATION FREQ (MHZ)	COMPRESSION OF LOC. SIGNAL IN DB	FREQ DEV. FOR XMOD CALC. (KHZ)	% AMMOD CAUSED BY STAT.
90.3	-0.0	40.	0.00
93.7	-0.0	40.	0.00
94.5	-0.0	40.	0.00
96.5	-0.0	40.	0.00
99.5	-0.0	40.	0.00
104.7	-1.1	40.	0.07
106.9	-4.5	40.	0.52
107.7	-8.6	40.	1.48

******CROSS COMPRESSION GREATER THAN 1, THIRD ORDER MODEL OF RECEIVER NO LONGER VALID. TOTAL PERCENT MOD., NOT CONSIDERING CROSSCOMPRESSION = .40 COMPRESSION FACTOR 1.155 DESIRED SIGNAL COMPRESSION IN DB = ********TOTAL PERCENT AM MODULATION =*****

Table 18. Cross-Modulation Due to Interfering Signals. Receiver at LOM Location.

RECEIVER FREQUENCY IS 110.30 RECEIVER BANDWIDTH IS 40.0 KHZ
FREQUENCIES WHICH PRODUCE INTERMOD INTERFERENCE ARE:

F1	F2	F3	IM TYPE	IM CENTER FREQ
93.7	106.9	90.3	F1 + F2 - F3	110.30

IM LEVEL IN DBM, NO FM STAT. MODULATION

-82.8

Table 19. Intermodulation Interference. Receiver at LOM Location.

PRINTOUT OF SIGNAL LEVEL COMPUTATIONS

STATION FREQ (MHZ)	MILES FROM RECEIVER	STATION POWER IN DBM	FREE SPACE ATTEN-DB	NAV ANTENNA LOSS-DB	RECVR INPUT FILTER ATTEN DB	SIGNAL LEV AT RFAMP IN DBM
90.3	5.7	77.0	90.5	18.2	21.0	-46.7
93.7	3.2	80.0	85.8	14.8	18.4	-33.1
94.5	5.7	80.0	90.9	14.0	17.8	-36.8
96.5	5.7	77.0	91.1	12.0	16.3	-36.5
99.5	3.2	80.0	86.4	9.0	14.1	-23.5
104.7	5.7	80.0	91.8	3.8	8.4	-18.0
106.9	5.7	80.0	92.0	1.6	5.1	-12.7
107.7	5.7	80.0	92.1	0.8	3.9	-10.8
LOCALIZER SIGNAL LEVEL CALCULATIONS:						
110.3	11.5	46.0	98.4	0.0	0.0	-46.3

Table 20. Signal Levels at Location (2) in Figure 13.

*****************CROSS MODULATION CALCULATIONS*****************

STATION FREQ (MHZ)	COMPRESSION OF LOC. SIGNAL IN DB	FREQ DEV. FOR XMOD CALC. (KHZ)	% AMMOD CAUSED BY STAT.
90.3	-0.0	40.	0.00
93.7	-0.0	40.	0.00
94.5	-0.0	40.	0.00
96.5	-0.0	40.	0.00
99.5	-0.1	40.	0.00
104.7	-0.4	40.	0.02
106.9	-1.4	40.	0.14
107.7	-2.3	40.	0.27

TOTAL PERCENT MOD., NOT CONSIDERING CROSSCOMPRESSION= 0.6 COMPRESSION FACTOR 0.488 DESIRED SIGNAL COMPRESSION IN DB= 5.2 TOTAL PERCENT AM MODULATION= .43

Table 21. Cross-Modulation Due to Interfering Signals. Receiver at Location (2).

RECEIVER FREQUENCY IS 110.30 RECEIVER BANDWIDTH IS 40.0 KHZ
FREQUENCIES WHICH PRODUCE INTERMOD INTERFERENCE ARE:

F1	F2	F3	IM TYPE	IM CENTER FREQ
93.7	106.9	90.3	F1 + F2 - F3	110.30

IM LEVEL IN DBM, NO FM STAT. MODULATION
-83.5

Table 22. Intermodulation Interference. Receiver at Location (2).

From these results it is seen that the resulting cross-modulation due to "brute-force" interference is approximately .43 percent, assuming the frequency deviation and receiver front end characteristics given earlier. Whether or not this creates a particular significant level of interference would be a matter of judgment and more investigation of this important decision criterion is required.

(d) Receiver at Location (3).

The results to be expected when the receiver is at location (3) are given in Tables 23, 24 and 25. As in the previous case whether there is an interference problem at this position is a matter of the "definition of interference". Since the resulting AM modulation due to cross-modulation resulting from the interfering signals is only .16 percent and the intermod level is -89 dBm, it is expected that there would be minimal interference at this location.

VIII CDI MODEL

A. Analytical Model. In order to predict the effects of interfering FM stations on the navigational aids it is necessary to have an analytical model of the CDI Circuitry. Thus far, the model has been capable of predicting responses throughout the receiver to the AM-detector output circuitry.

Figure 14 shows a block diagram of the audio processing circuitry of the NAV 11 receiver, which is assumed to be typical of those to be encountered in practice. Figure 15 shows a more detailed schematic diagram of the circuitry of interest.

After rather detailed and involved investigations the CDI response was modeled by a relative simple relationship, given in (50) below

$$CDI = k\,(V_{B1} - D\,V_{B2}) \tag{50}$$

where

CDI = the measured voltage $V_{E404} - V_{E407}$ as indicated in Figure 15 (measurements are made with a DC DVM).

V_{B1} = RMS voltage at the base of Q 409

V_{B2} = RMS voltage at the base of Q 410

D = Ratio of the RMS voltage at the base of Q409 to the RMS voltage at the base of Q 410 with CDI = 0 μ amp

$$D = \left.\frac{V_{B1}}{V_{B2}}\right|_{CDI = 0.} \tag{51}$$

PRINTOUT OF SIGNAL LEVEL COMPUTATIONS						
STATION FREQ (MHZ)	MILES FROM RECEIVER	STATION POWER IN DBM	FREE SPACE ATTEN-DB	NAV ANTENNA LOSS-DB	RCVR INPUT FILTER ATTEN DB	SIGNAL LEV AT RFAMP IN (DBM)
90.3	8.0	77.0	93.5	18.2	21.0	-49.7
93.7	3.1	80.0	85.6	14.8	18.4	-32.8
94.5	8.0	80.0	93.9	14.0	17.8	-39.7
96.5	8.0	77.0	94.1	12.0	16.3	-39.4
99.5	3.1	80.0	86.1	9.0	14.1	-23.2
104.7	8.0	80.0	94.8	3.8	8.4	-21.0
106.9	8.0	80.0	94.9	1.6	5.1	-15.6
107.7	8.0	80.0	95.0	0.8	3.9	-13.7
LOCALIZER SIGNAL LEVEL CALCULATIONS:						
110.3	14.4	46.0	100.3	0.0	0.0	-48.3

Table 23. Signal Levels at Location (3).

*****************CROSS MODULATION CALCULATIONS*****************			
STATION FREQ (MHZ)	COMPRESSION OF LOC. SIGNAL IN DB	FREQ DEV. FOR XMOD CALC. (KHZ)	% AMMOD CAUSED BY STAT.
90.3	-0.0	40.	0.00
93.7	-0.0	40.	0.00
94.5	-0.0	40.	0.00
96.5	-0.0	40.	0.00
99.5	-0.1	40.	0.00
104.7	-0.2	40.	0.01
106.9	-0.7	40.	0.06
107.7	-1.1	40.	0.12

TOTAL PERCENT MOD., NOT CONSIDERING CROSSCOMPRESSION= 0.01 COMPRESSION FACTOR 0.235 DESIRED SIGNAL COMPRESSION IN DB= 2.3
PERCENT AM MODULATION= 0.16

Table 24. Cross-Modulation Due to Interfering Signal. Receiver at Location (3).

RECEIVER FREQUENCY IS 110.30 RECEIVER BANDWIDTH IS 40.0 KHZ
FREQUENCIES WHICH PRODUCE INTERMOD INTERFERENCE ARE:

F1	F2	F3	IM TYPE	IM CENTER FREQ
93.7	106.9	90.3	F1 + F2 - F3	110.30

IM LEVEL IN DBM, NO FM STAT. MODULATION
-89.1

Table 25. Intermodulation Interference. Receiver at Location (3).

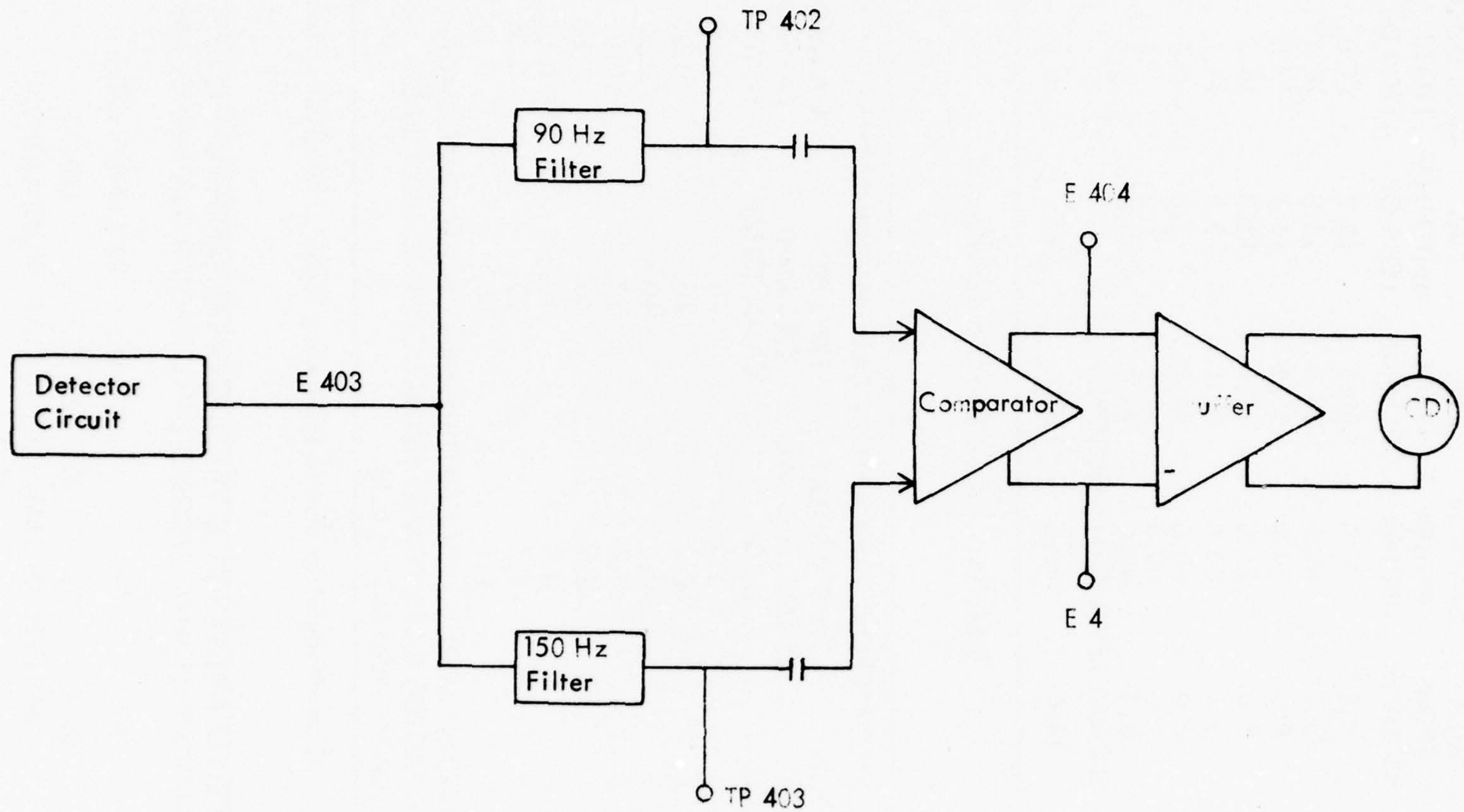


Figure 14. Block Diagram of Audio Processing Circuit of NAV 11.

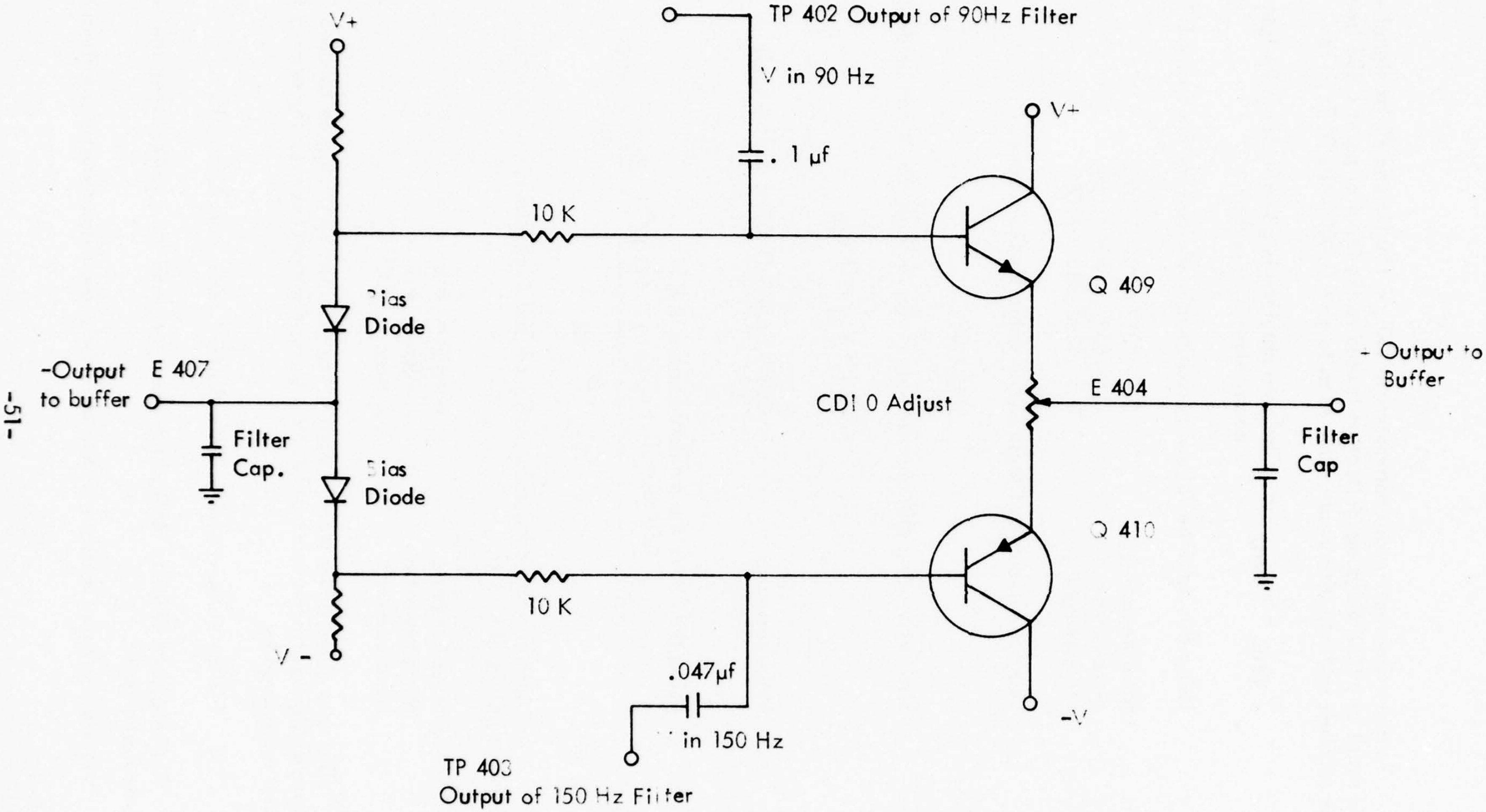


Figure 15. Simplified Schematic of Comparator
Circuitry of NA / 11 Receiver.

To determine the various parameters in (50), a 150 Hz and 90 Hz signal which would result in a 0.0 microamp deflection is used as the input at point E 403 (see Figure 14) of the receiver and adjustments are made so as to give 0.000 volts D.C., i.e.

$V_{E404} - V_{E407} = 0$. The data obtained is given in Table 26 (see measurements a, d and g).

Using this data the following results are obtained for the factor D in (50):

Measurement a	$D = .701/.640 = 1.095$
Measurement d	$D = .658/.604 = 1.084$
Measurement g	$D = .638/.585 = 1.090$

Using the average of these as the value for D we have,

$$D = 1.09 \qquad (52)$$

Similarily using (50) and the data given in Table 26, k can be determined i.e.,

$$\frac{CDI}{k} = V_{B1} - D\,V_{B2} \qquad (53)$$

Measurement b $\qquad \frac{CDI}{k} = .774 - (1.09)\,(.563) = .160$

Using the above the measured value of k is (54)

$$k \text{ measured} = \frac{CDI \text{ meas (i.e. } V_{E404} - V_{E407})}{V_{B1} - D\,V_{B2}} = \frac{.064}{.160} = .400$$

Similarily using measurements c, e and f one can obtain several independent values of k, i.e.,

Measurement c	k meas = .416
Measurement e	k meas = .412
Measurement f	k meas = .4005

The data given under measurement h was obtained by adding an assumed interference signal with frequency of 105 Hz. Using the model above, the desired CDI response calculated by

$$CDI \text{ calculated} = .4\,(.744 - (1.09)\,(.594)\,) = .0385 \text{ volts}$$

The measured value is .040 which gives less than 4% error between the measured and calculated result.

For completeness several points relative to these measurements are given in Table 27.

Measurements	Voltage at the Base of Q409 (1)	Voltage at the Base of Q410 (2)	Difference in Voltage (3) at Test Points E406 and E407
a	0.701	0.640	0.000
b	0.794 (4)	0.563	0.0646
c	0.635	0.715	-0.060
d	0.658	0.604	0.000
e	0.606	0.616	-0.0270
f	0.670	0.546	0.0300
g	.638	.585	.0000
h	.744 (5) average	.594 average	.040 average

(1) AC voltage measured with HP 3476B DVM
(2) AC voltage measured with HP 3476 DVM
(3) DC voltage measured with Digitek DVM
(4) Measured with 50 μ amp deflection on ratio generator
(5) Measured with 105 Hz tone added to 90/150 Hz signal given in measurement (g)

Table 26. Measurements of CDI Voltages.

Reference Notes	
(1)	Measurement h is obtained taking the average of the maximum and minimum voltage readings. The variation of the voltage is due to the beat between the 105 Hz and the 90 Hz signal.
(2)	For all measurements a 200 μf capacitor was placed across C 409. This makes the voltages at the emitters of Q409 and Q410 the halfwave rectified output of the signals appearing at their bases.
(3)	The capacitors C407 and C408 which couple the signals from TP 402 and TP 403 into the comparator circuit have significant impedance at 90 Hz and 150 Hz. Therefore, to correctly calculate the CDI deflection, AC voltage measurements must be performed at the bases of Q409 and Q410.
(4)	CDI output was measured at the output of comparator circuit to prevent errors arising due to the nonlinearity of buffer circuit.

Table 27. Reference Notes Relative to Measurements in Table 26.

B. Modeling Receiver Filters. In order to predict the CDI response, it is necessary to model the output of the 90 and 150 Hz filters. Likewise to predict the amount of audio interference caused by FM stations, the audio filter characteristics must be known. Figure 16 shows the measured characteristics of the 90 and 150 Hz filters. The audio characteristics are shown in Figure 17 and the detector characteristics in Figure 18.

Since the output of the 90 and 150 Hz filters would be highly dependent on the properties of the modulation on the FM interfering signals*, the filters were modeled using the following technique:

(1) Assume the input to the 90 and 150 Hz filters to be "white" noise, i.e., the modulation is assumed to have a constant spectral density over the passband of the filters.

(2) Determine the noise equivalent bandwidth** of the 90 and 150 Hz filters. For applying the model it would be necessary for the user to obtain or measure this information.

(3) With the information contained in (1) and (2) the RMS outputs of the 90 and 150 Hz can be determined, which allows us to compute the modulation factors.

Figure 17 shows the filters with the same noise equivalent bandwidth as the 90 and 150 Hz filters used in the computer program.

Table 28 compares the results obtained from the computer program to measured results with IM present and with desired signal noise modulated. (Details in Appendix D)

These results were compared with those obtained using a tone modulated intermod formed from the FM signal as before.

The results show the good correspondence between the modulation caused by IM and that caused by a noise source, justifying the analysis of IM using a noise source model. It also shows that the computer program accurately predicts the amount of interference.

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*See Appendix D, Section 2

**See Appendix E for details in determining the noise equivalent bandwidth.

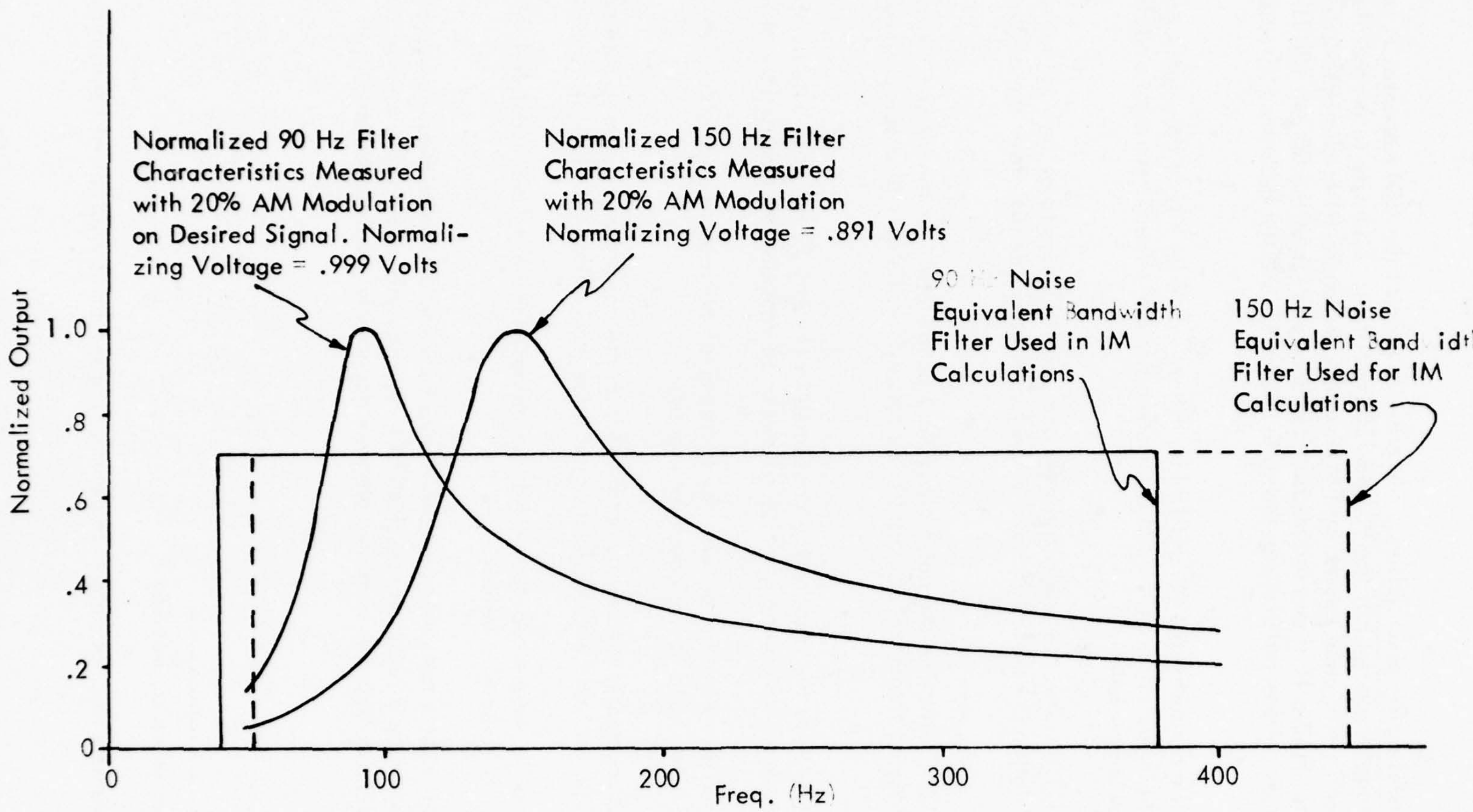

Figure 16. 90/150 Hz Filter Responses.

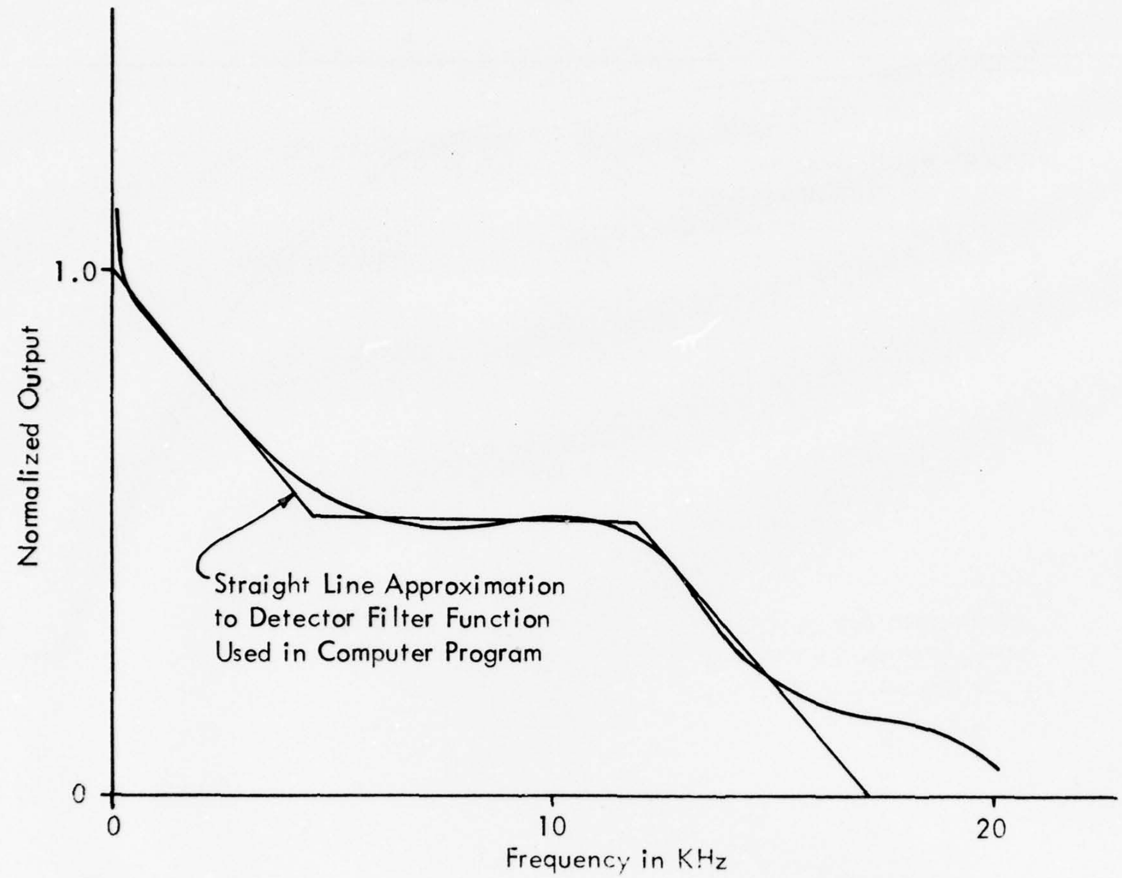

Figure 17. Normalized Detector Filter Characteristics Measured with 20% Modulation on Desired Signal Normalizing Voltage = .250 Volts.

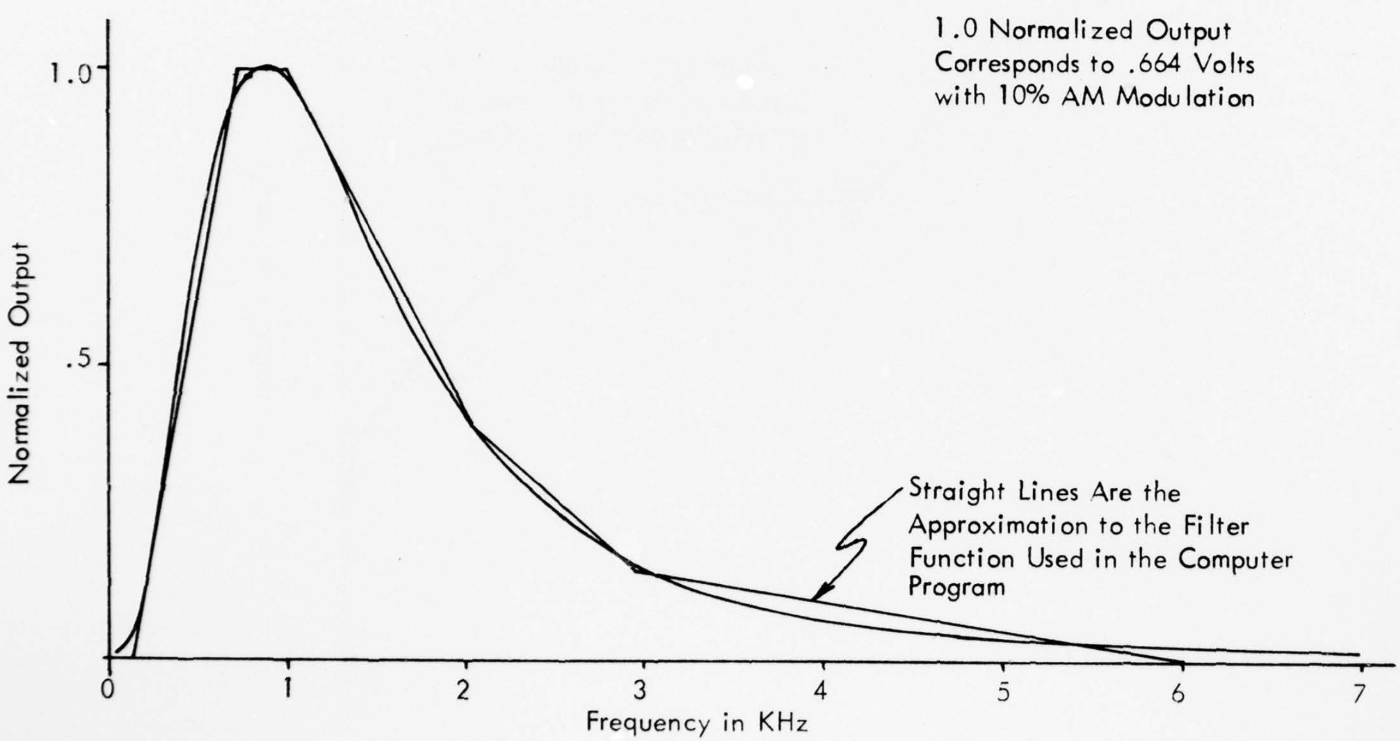

Figure 18. Audio Filter Characteristics.

Filter	Measured		Theoretical
	% RMS Modulation with desired signal noise modulated (1)	% RMS Modulation due to IM Measured (2)	% RMS Modulation due to IM Theoretical results from Computer Program
Detector	12.1%	12.1%	12.1%
Audio	5.0%	4.7%	5.7%
150 Hz Filter	2.4%	2.5%	2.4%
90 Hz Filter	2.0%	2.0%	1.8%

(1) Desired signal present only, desired signal AM modulated by General Radio Model 1381 Random Noise Generator.

(2) Desired signal present, IM formed by 2 FM tone modulated stations.

Table 28. Summary of RMS Modulation Measurements and Calculations.

C. Effects of High Level Modulation on CDI Reading. During the experimental verification of the model several difficulties were encountered which needed study. One particularly important problem was that of detector overload (or clipping). The net result of these effects is a desensitization of the receiver.

The procedure for determining these effects was to input a desired signal of 108.5 MHz modulated with a standard 90/150 localizer signal and another signal at lower amplitude with a frequency slightly offset from the 108.5 MHz. In this experiment, 108.501 MHz was used which results in an additional 1KHz sideband in the IF stage. This 1KHz signal was detected along with the 90 and 150 Hz signals. This interfering 1KHz signal caused the detector to overload and the detected signal was clipped. The result is that the 1 KHz sideband signal simulates the effects of a high level intermod. In theory this should have no effect on the receiver; however, due to the overloading of the detector it does cause a significant desensitization problem.

The 90 and 150 Hz filters have very narrow bandwidth, which eliminates a considerable amount of the distortion. In order to obtain significant intermod interference, it is necessary that the intermod level be significantly high so as to cause overload

distortion at the detector. From previous measurements (see Appendix D), it was determined that an intermod carrier level which is 10 dB less than the desired signal (which results in a modulation factor of .45 and a percent modulation of approximately 12% at the detector output) causes significant interference. In this case the voltages at the outputs of the 90 and 150Hz filters were measured to be .1 volts, which corresponds to an equivalent modulation of about 2%. If the intermod level were increased by three times to give an RMS modulation of 36%, the equivalent modulation at the output of the 90/150 Hz filters would be approximately 6%.

As an example of the use of the techniques consider the following:

(a) Assume the localizer signal such that it produces 60 μA CDI response, then DDM = 60 (.155/150) = .06 or 6%

(b) In this case the receiver would see 23% modulation at the 90 Hz filter output and 17% modulation at the 150 Hz filter output.

(c) Assuming an intermod present which results in an equivalent of 6% modulation at the 90 Hz filter output, the modulation would be

$$\sqrt{((.06)^2 + (.23)^2)} \times 100 = 23.8\%$$

In a similar fashion the 150 Hz filter output would be

$$\sqrt{((.06)^2 + (.17)^2)} \times 100 = 18.1\%$$

Using these results the CDI with the assumed interference present would be:

$$\text{CDI} = (23.8-18.1)\ (150/15.5) = 55.1\ \mu\text{A}$$

This corresponds to an 8% reading change from the CDI reading with no interference present, which would be a relatively small change in CDI reading. On the other hand with a modulation of 40%, the CDI (assuming 60 μA without interference) changes by 20% or gives a reading of 48 μA due to limiting or clipping of the detector output.* Therefore, limiting due to overloading is the significant problem affecting the CDI reading.

IX COMPUTER PROGRAM

In Section VI an illustrative example of the calculations required assuming only two interfering FM signals was given. If there exists more than two interfering signals, the amount of calculations required becomes excessive for hand computations. A computer program was written which is capable of making the required computations for any number

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*See Appendix F for detailed data.

of interfering signals (limited only by the computer facilities available to the user).

The program performs the following tasks:

(1) Calculations of the signal levels at the RF amp input due to FM stations.

(2) Cross-modulation and cross-compression calculations.

(3) Printout of intermodulation producing stations.

(4) Calculations of % AM modulation due to IM.

(5) Computation of the effects of interference on CDI.

(6) Combined cross-modulation and intermodulation interference calculations.

Appendices G and H describe the computer program in detail and in Appendix G is a sample printout from the program.

X CONCLUSIONS AND RECOMMENDATIONS

The research reported herein has culminated in analytical techniques capable of predicting possible interference of airborne communication and navigation receivers due to commercial FM broadcast stations. Approximate analytical models of the receiver were developed which could be specified by rather simple measurements.

Both the effects of "brute-force" interference and intermodulation distortion can be readily handled by the model. It was found, as was expected, that the majority of the nonlinearities were due to saturation of the RF amplifier. A relative simple analytical model using a third-order nonlinearity was found to be satisfactory for interference levels of approximately 0 dBm and below. For higher signal levels than this, the model does not account for limiting and other effects; however, for interfering signal levels of this strength, it is expected that an interference problem would exist.

Measurement techniques involving only a monitoring of the AGC voltage were developed which allows for the determination of the various parameters of the nonlinear model. It was found that most of these parameters could be assumed relatively constant over a wide range of input signal levels. In addition to the determination of the various parameters of the nonlinear model, the following information must be known:

(1) RF frequency response

(2) IF frequency response characteristics (bandwidths and skirt attenuation characteristics)

With this information the signals at the output of the IF-amplifier can be predicted. In most cases it was found that the best way to handle the above characteristics was to specify the overall frequency characteristics in terms of an input filter skirt slope attenuation characteristics and an overall frequency response characteristic of the RF-amplifier output circuitry and the IF-amplifier. For the latter both ideal bandpass and triangular bandpass characteristics were used. Using the above analytical model, signals at the input to the audio detector can be predicted.

Models of the audio detector circuit and the 90 Hz and 150 Hz filters in the case of navigation receivers were developed. This requires the frequency characteristics of the audio circuit and the 90 Hz and 150 Hz filters either be known or determined by measurements. It is found that the interference at the output of the 90 Hz and 150 Hz is rather small due to very narrow bandwidths of these filters. An analytical model of CDI (course deviation indicator) was determined which could predict the effects of the interfering signals.

Investigations were performed for determining the signal levels at the input to the receiver given the station power and it was found that a satisfactory model to use was the free space attenuation formula, along with an empirical correction factor to account for the vehicle antenna loss. The empirical correction used was to assume 1 dB/1 MHz attenuation for signals below 108.5 MHz.

A computer program using the developed models and techniques was written which can calculate and predict interference due to any number (limited only by the user computer facilities) of FM stations. The program uses the measured characteristics of the vehicle receiver to predict the amount of interference due to high power FM stations. The program assumes sinusoidal modulation on the FM signals and that the interference is due to 3rd order nonlinearities in the RF amp of the receiver.

The user must supply the following information to analyze an interference situation: Number of FM stations, receiver frequency, distortion parameter $3K_3/2K_1$. For each FM station, the following information is required: Station frequency, modulation frequency and modulation index, distance from the receiver and station power level. Localizer distance from the receiver and power level is also needed.

Although the program was written as general as possible, there are some specific limitations and these are:

(1) A modulation index of 75 is a practical limit on the maximum modulation index that the program will accept. Modulation indices higher will cause extremely long program execution times. A modulation index of 75 corresponds to a maximum frequency deviation of 75 KHz with a modulation frequency of 1 KHz.

(2) The program assumes that the modulation frequencies of the FM stations are not harmonically related. For example frequencies of 1000 Hz and 400 Hz are related whereas 1000 Hz and 398 Hz are not. The intermodulation due to stations with harmonically-related modulation frequencies has components which occur only at certain frequen-

cies relative to the IM carrier and does not exhibit the "noise-like" (realistic) properties which are assumed for IM calculations. Harmonically-related modulation frequencies will be treated as though they were not related by the program. Therefore, when using harmonically-related frequencies such as 1000 Hz and 400 Hz, it is advisable to check the results to see if the same results are obtained as with frequencies of 1000 Hz and 398 Hz.

Although satisfactory analytical models and techniques have been developed in this research, there were certain key items identified during the program which are recommended for further research.

(1) The determination of reliable statistical criteria which would allow for realistic decision making regarding interference potentials and which can be adequately substantiated thus providing a strong, defendable technical basis for future judgment and decisions concerning station allocations.

(2) Receiver modeling improvement, either by extending the current model or the use of more sophisticated models than are currently being used.

(3) A written specification and verification of field testing procedures for evaluating interference problems.

Although the above list is not an exhaustive list of identifiable items requiring further investigation, those items on the list are believed to be of immediate concern and importance for the proper enhancement of the results reported in this research. Brief descriptions of the items recommended for further research are given below.

A. Statistical Model.

1. Type of Modulating Signals to be Assumed. The research reported herein has used primarily single tone modulated FM signals in the development of the model. To a limited extent, "white" noise as a source of modulation has also been considered. Since the CDI in a navigation receiver is preceded by rather narrow bandpass filters, the type of modulation will have a considerable bearing on the CDI response.

Since the receivers will be operating in a real world environment, there is a need for a statistical study to determine a model which would be truly representative of real world modulations. Without this, one is left with only the option of talking about probable "worst" case effect, which would be hardly a convincing argument in the real world.

2. Statistical Basis for Interference Decision. The RMS value of the output of an envelope detector due to the interfering signals was used as a parameter to determine a potential interference problem. It is possible that other parameters (statistics) might be a better indicator of potential interference problems. For example, peak modulation might be a more realistic parameter on which to base decisions regarding potential interference problems.

There is a need to investigate and determine which parameter or parameters are useful and reliable for basing predictions of potential interference problems. It is proposed that various parameters be investigated and evaluated and that these be related to real world occurrences. The analytical methods and parameters would be substantiated by experimental documentation.

3. Decision Criterion. For any mathematical or analytical model to be useful, in a practical sense, one needs to know the implications of the results obtained, and exactly how realistic they are. To illustrate this rather involved statement, consider discussed criterion used in deciding a potential interference problem. The means of deciding whether or not interference would occur was to simply postulate the following decision rule using the RMS output of the envelope detector (V_o) as the statistic (parameter):

Decision Rule

If V_o *(RMS output of envelope detector due to interfering signals)* $\geq T$ *decide* in favor of an interference problem, i.e., decide that there is a potential interference problem.

If $V_o < T$ decide that there is no significant potential interference problem. The consequences of the above are summarized below:

Actual Condition	$V_o \geq T$	$V_o \leq T$
Interference	Correct Decision	Incorrect Decision
No (minimal) Interference	Incorrect Decision	Correct Decision

Summary of the Results of Decision.

The peak-modulation index and the RMS output of an envelope detector were used as the parameter (statistic) on which the decision was made. In particular, for checking the model, T was arbitrarily set at some constant value. It was possible to provide a "profile" of potential interference problems in terms of FM station (or FM stations) locations and power relative to usable navigation signals. This allows for predicting the effects of adding

one or more FM stations in the near vicinity, or the results to be expected if signal powers are changed.

In order to provide realistic and convincing arguments, regarding potential interference problems, two areas need further study, i.e., what decision rule and what statistic should be used to provide realistic and convincing arguments regarding potential interference problems.

Additional research is recommended which would result in the determination of useful and reliable decision rules and parameter (these may be different for navigation and communication receivers) for predicting potential interference problems. The results are to be presented in terms of a statistical model using probability measures of the errors associated with the decision rules. This could be accomplished by specifying a "confidence" interval describing the results of decisions regarding interference problems and/or probabilistic measures of incorrect decisions.

B. Model Improvement. Although results obtained here have shown that the analytical techniques used for modeling the propagation and the receiving of interfering and/or desired signals, in conjunction with the all-important model of the airborne navigation and communication receivers in the presence of a multi-signal environment are useful and applicable, there is a need for model enhancements and improvements. Enhancements and improvements are needed in the two areas of concern, i.e., (1) propagation model and (2) receiver model.

(1) Propagation Model. There is a need for providing an improved model of the propagation of both the desired and interfering signals that would include more realistically the effects of transmitting and aircraft receiving antennas. The problems associated with modeling an aircraft antenna are of considerable difficulty and the solutions, at most, only approximate in nature. This complication is due in large part to the presence of the aircraft. It is suggested that investigations be undertaken which would result in a more realistic model of the receiving antennas on board selected aircraft. For these investigations it is suggested that selected "reference" aircraft be identified and that each of these be considered and the antennas and aircraft be modeled as a system. Such a model would include coupling characteristics between key antennas on the aircraft. It is expected that numerical moment method techniques performed with the aid of a digital computer will be required to obtain these results. The end result of such investigations would be a computer program which would be capable of modeling certain selected aircraft to a high degree of accuracy. Theoretical results should be verified by experimental documentation.

A second phase of this investigation would involve a study which would enumerate the results and expected consequences of simplifying the propagation model. Trade-off studies involving complexity vs. accuracy would be performed.

The results of the previously-mentioned investigations would allow for the realistic and accurate modeling of the signal propagation from the transmitting to the receiving antenna.

(2) Receiver Model. It has been demonstrated that the third-order receiver model developed for predicting interference effects is useful in predicting the effects of multiple interfering signals on aircraft navigation and communication receivers; however, it would be desirable to improve the accuracy of these predictions. It is recommended that considerations be given to enhancing the existing receiver model in order to improve the accuracy of the predictions, along with investigations of other modeling schemes.

In particular, it is suggested that enhancement of the model be made so as to be able to consider the effects of higher signal power levels either due to more interfering signals or higher radiated power levels. It has been shown that the accuracy obtained using the simple third-order model is limited at power levels of 0 dBm or higher.

It is recommended that research on the receiver model be continued and the best way to enhance and extend the regions of validity of the receiver model be determined. In particular, investigations using higher order terms in the existing model and a comparison of these techniques in terms of complexity and accuracy with other models should be made.

In addition to the above important areas, effects of impedance mismatches, reflection coefficients, etc., should be considered.

Completion of these investigations along with the results obtained here would make a complete package which would allow the user the flexibility of using a model of just sufficient complexity to fulfill needed requirements. In some cases a very simple model could be used to obtain results within the necessary requirements, while on the other hand it may be necessary to use a rather complex model to obtain reliable results.

C. Standard Test Procedure. Efforts reported herein have been specifically for the purpose of development and experimental testing of analytical models. A "Standard Test Procedure" should be defined which would allow the engineer to set up an experimental test using signal generators with specified modulations and antennas that would simulate potential interference problems.

It is suggested that further research be performed which would identify such things as signal levels, modulating levels and signals, antennas, etc. This would allow an engineer to set up an experimental test which would realistically simulate the potential interference problems being considered.

D. Interference Profile Mapping of Potential Airport Facilities. It is recommended that further work be performed on detailed investigations of certain selected existing and/or proposed new airport facilities as identified by FAA regarding the potential of an interference problem existing and possibilities of such a situation developing. Typical applications would be to consider a specific airport and all possible interfering signal sources in the near vicinity along with their respective power levels, and signal frequencies, and using this data, calculations would be made to determine a "profile" of the interference potentials existing. These "profiles" would be given in terms of minimum distances for the establishment of additional FM-stations, effects of increased power levels, etc. These

"profiles" would be an indicator of how potentially close a particular facility is to having an interference problem.

Similar techniques as described above could be applied to proposed new facilities as identified by FAA personnel. Such results would be valuable in determining new sites and the consequences of the selections could easily be determined.

XI. ACKNOWLEDGMENTS

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XII. REFERENCES

[1] Chang, K.Y., "Intermodulation Noise and Products Due to Frequency Dependent Nonlinearities in CATV Systems", IEEE Transactions on Communications, Vol. com-23, No. 1, pp. 142-155, January 1925.

[2] Bennett, W.R., "Cross-Modulation Requirements on Multi-Channel Amplifiers Below Overload", Bell Syst. Tech. J., Vol. 19, pp. 587-610, October 1940.

[3] Simons, K.,"The Decibel Relationships Between Amplifier Distortion Products", Proc. IEEE, Vol. 58, pp. 1071-1086, July 1970.

[4] Glave, F.E., "A Statistical Approach to the study of Intermodulation Noise", Bell-Northern Research, Rep. TM 8260-1-66, July 1966.

[5] Wiener, N., "Non-linear Problems in Random Theory," Cambridge, Mass.: Tehcnology Press; and New York: Wiley, 1958.

XIII. BIBLIOGRAPHY

Bedrosian, E., and S. O. Rice, "Distortion and Crosstalk of Linearly Filtered Angle-Modulated Signals", Proc. IEEE, Vol. 56, pp. 2-13, January 1968.

Bedrosian, E., and S. O. Rice, "The Output Properties of Volterra Systems (Nonlinear Systems with Memory), Driven by Harmonic and Gaussian Inputs", Proc. of IEEE, Vol. 59, pp. 1688-1707, No. 12, 1971.

Mircea, A., E. Bedrosian, and S. O. Rice, "Further Comments on Distortion and Crosstalk of Linearly Filtered, Angle-Modulated Signals", Proc. IEEE (letter), Vol. 57, pp. 842-844, May 1969.

Narayanan, "Transistor Distortion Analysis Using Volterra Series Representation", Bell Syst. Tech. M., Vol. 46, pp. 991-1023, 1967.

Narayana, "Application of Volterra Series to Intermodulation Distortion Analysis of Transistor Feedback Amplifier", IEEE Trans. Circuit Theory, Vol. CT-17, pp. 518-527, November 1970.

Rice, S. O., "Second and Third Order Modulation Terms in the Distortion Produced When Noise Modulated FM Waves Are Filtered," Bell Syst. Tech. J., Vol. 48, pp. 842-844, January, 1969.

XIV. APPENDICES

A. Theoretical and Experimental Measurements Using Model and an FM-Interfering Signal. Theoretical and experimental measurements were obtained using the proposed model for the RF-amplifier. For these investigations, the desired localizer signal was assumed to be a 108.5 MHz signal which was amplitude modulated in some cases by a 1000 Hz tone to allow for the determination of distortion at the output of the detector. The interfering signal was assumed to be an FM modulated signal of various signal strengths operating at 105.5 MHz. This signal was modulated by a 10 KHz sinusoid producing a modulation index of 6, resulting in an FM bandwidth of approximately 200 KHz. The interfering signal spectrum is illustrated in Figure A-1.

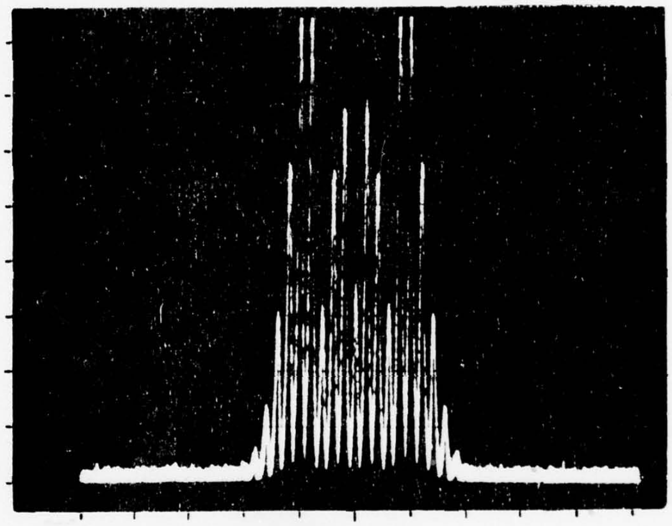


Figure A-1. Interfering Signal Spectrum; Modulation Index = 6; Bandwidth = 200 KHz.

Using this as the input signal and assuming no distortion due to input filtering of the FM spectral components it can be shown that the cross-modulation terms located near 105.5 MHz will result in only a compression term at the carrier frequency of the desired signal (108.5 MHz). Considering the effects of the input filter (.2 dB/100 KHz attenuation) on the FM spectral components theoretical calculations indicate the ratio of the first sideband to the carrier term to be -44 dB compared to a measured value of -42 dB. For the second sideband theoretical results predicted -92 dB which could not be measured. These results are illustrated in Figure A-2.

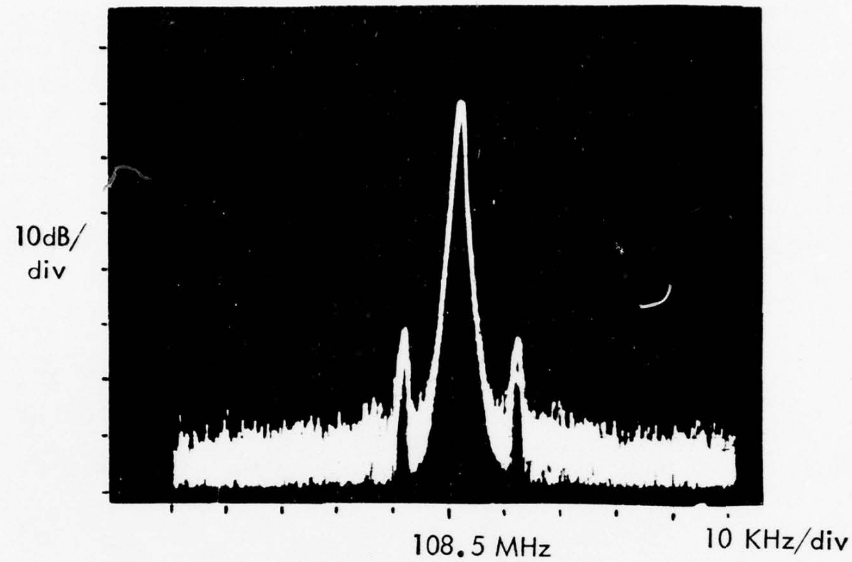


Figure A-2. Spectrum of Desired Signal (108.5 MHz) at RF-Amplifier Output. Desired Signal Strength -17 dBm (.03 volts); FM-Interfering Signal (105.5 MHz, $\beta = 6$; Bandwidth = 200 KHz) 0 dBm (.2 volts).

Figure A-3 shows the spectrum at the RF amplifier output with the desired signal at -47 dBm signal level with the interfering signal level the same as given for Figure A-2. The sidebands are not visible because of the residual noise.

Qualitative investigations of the distortion produced at the output of the detector were performed. Figure A-4 shows the detector output using a 1 KHz modulation signal with 10 percent modulation and no interfering signal present.

Figure A-5 shows the detector output when the desired signal is the same as described in Figure A-4 and the interfering FM signal of 0 dBm, as described in Figure A-1, is added.

Figure A-6 shows the detector output when a desired signal is reduced to -47 dBm.

Figure A-7 indicates the results obtained using a desired signal strength of -70 dBm (.1 mv) and no interfering signal. Figure A-8 shows the results of an interfering signal of 0 dBm (.23v) on this weak input desired signal. A significant amount of distortion due to the FM-interfering signal is observed.

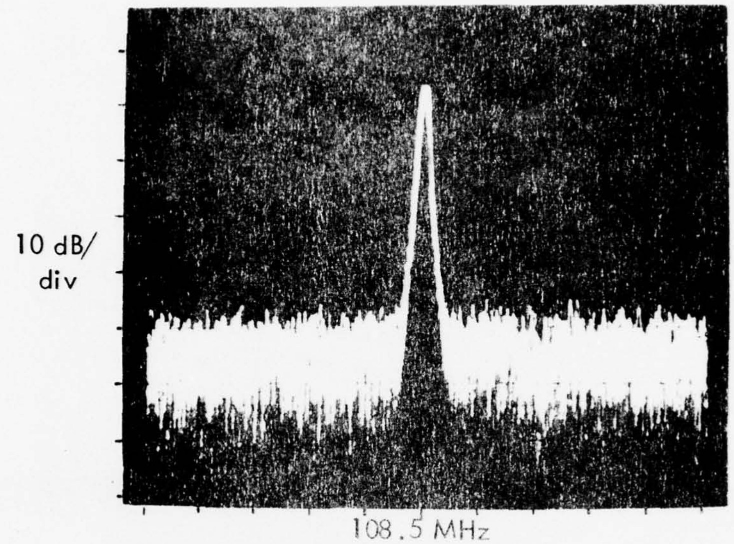


Figure A-3. Spectrum of Desired Signal (108.5 MHz) at RF-Amplifier Output. Desired Signal Strength -47 dBm (1 mv); FM-Interfering Signal (105.5 MHz; β = 6, Bandwidth = 200 KHz) 0 dBm (.2 volts).

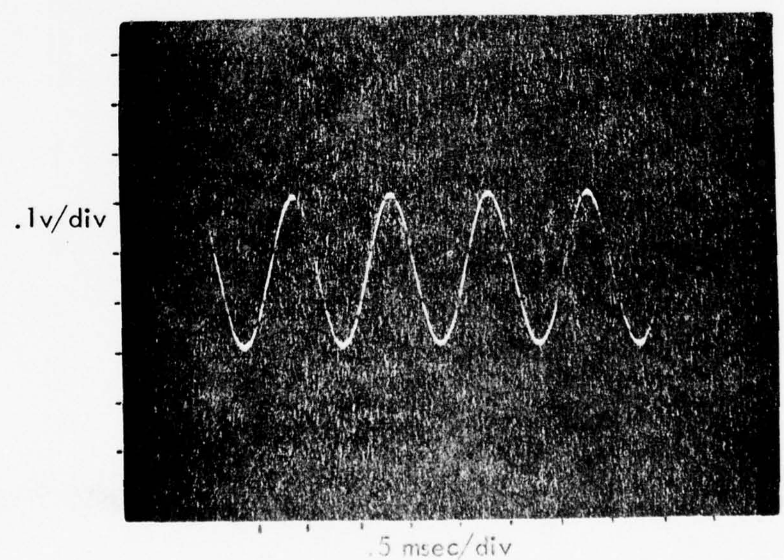


Figure A-4. Detector Output with No Interference. Carrier frequency = 108.5 MHz; Modulation frequency = 1 KHz; 10% Modulation.

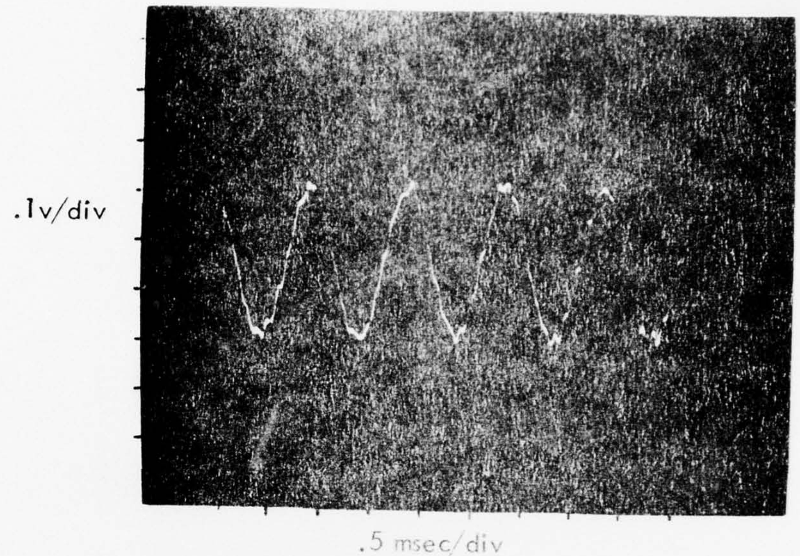


Figure A-5. Detector Output with Interfering FM-Signal (0 dBm) at 105.5 MHz. (Described in Figure A-3)

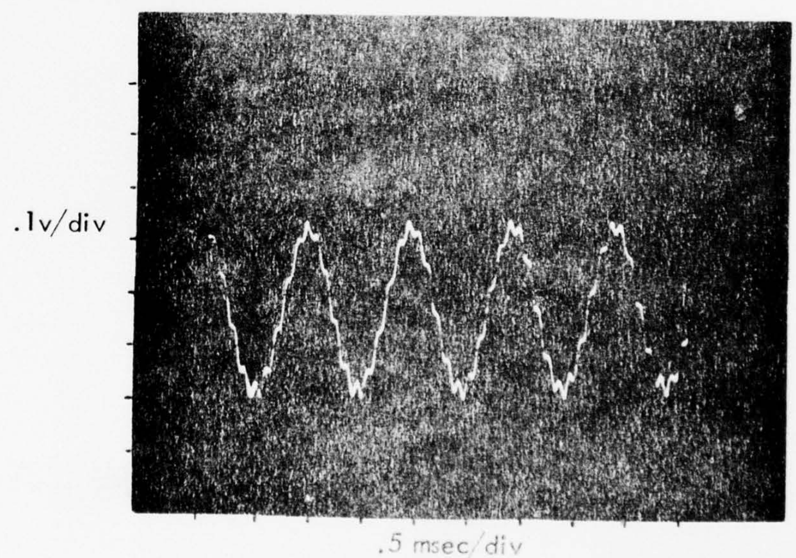
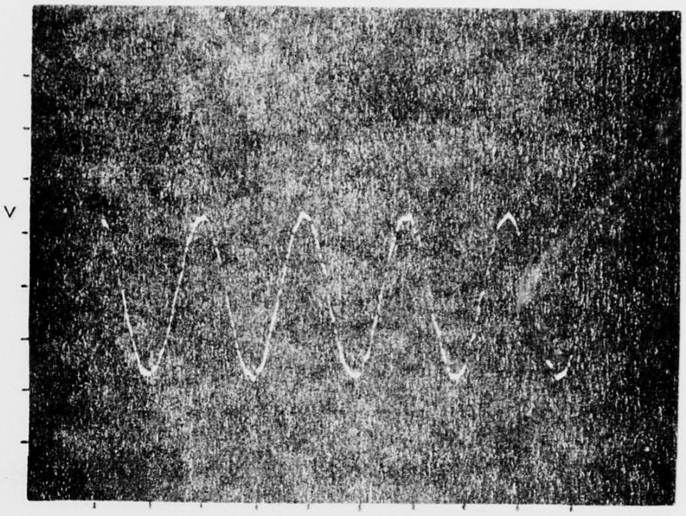


Figure A-6. Detector Output Using Input Signals Described in Figure A-2, with 10% Modulation on Desired Signal.

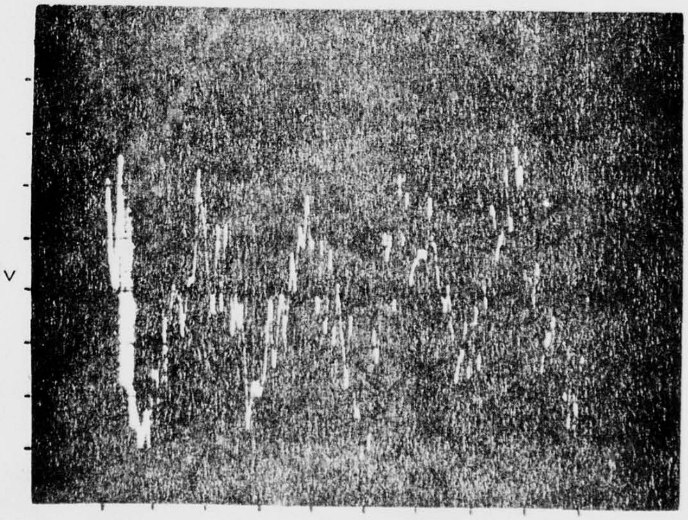
.1v/div



.5 msec/div

Figure A-7. Detector Output Desired Signal Level = -70 dBm, No Interfering Signal.

.1v/div



.5 msec/div

Figure A-8. Detector Output. Desired Signal Level = -70 dBm; Interfering Signal Level 0 dBm.

B. Filter Characteristics

1. Measurement of RF Amplifier Input Filter Characteristics $\alpha(\omega)$. The test setup to measure the RF amplifier filter characteristics $\alpha(\omega)$ is shown in Figure B-1.

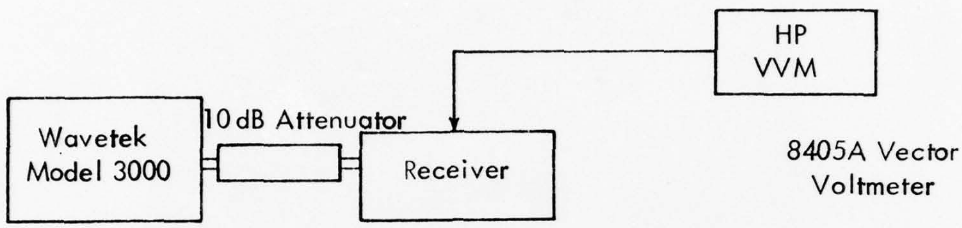


Figure B-1. Measurement Procedure for Obtaining $\alpha(\omega)$.

The voltage at the input to the gate of dual gate MOSFET of the RF Amplifier was measured as a function of Wavetek frequency. The voltage at the RF amplifier input was measured using a HP 8405A vector voltmeter.

The AGC voltage of the receiver was fixed and the signal level from the Wavetek 3000 was held constant.

The resultant filter characteristics measured were found to be shifted in frequency from the receiver frequency by 2 MHz. It was assumed that this was due to the capacitive loading of the vector voltmeter X10 probe used. Therefore, the characteristic was shifted over 2 MHz so that the resonant frequency of the filter is the desired frequency 108.5 MHz. Figure B-2 gives a simplified schematic of the Nav 11 front end.

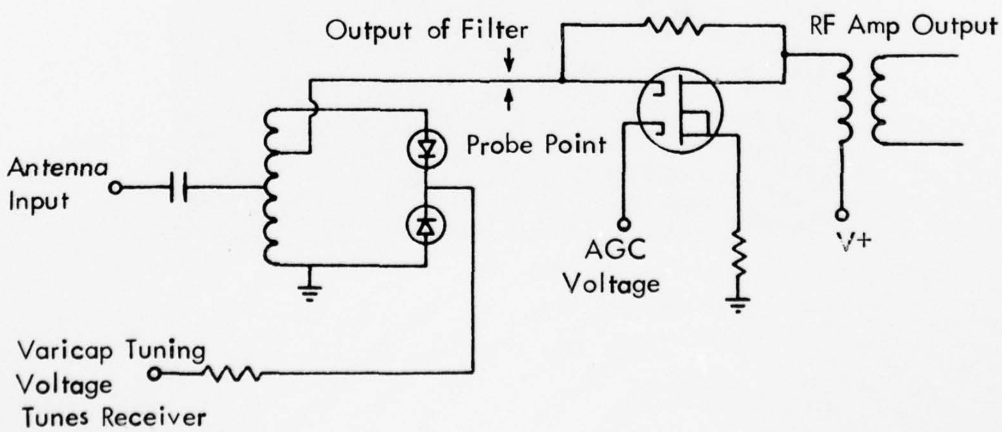


Figure B-2. Simplified Schematic of RF Front End of NAV 11 Receiver.

In order to verify that the RF Amplifier input filter characteristics were correct, cross-compression and intermodulation measurements were made varying the frequency of the interfering signals.

The intermod measurements given in Figure 4 of the main text shows that the $\alpha(\omega)$ characteristics measured result in constant K_3/K_1 (within experimental accuracy). The test procedure illustrated in Figure B-3 was used to measure cross-compression of the desired signal as a function of interfering signal frequency and the results give the following for $\alpha(\omega)$.

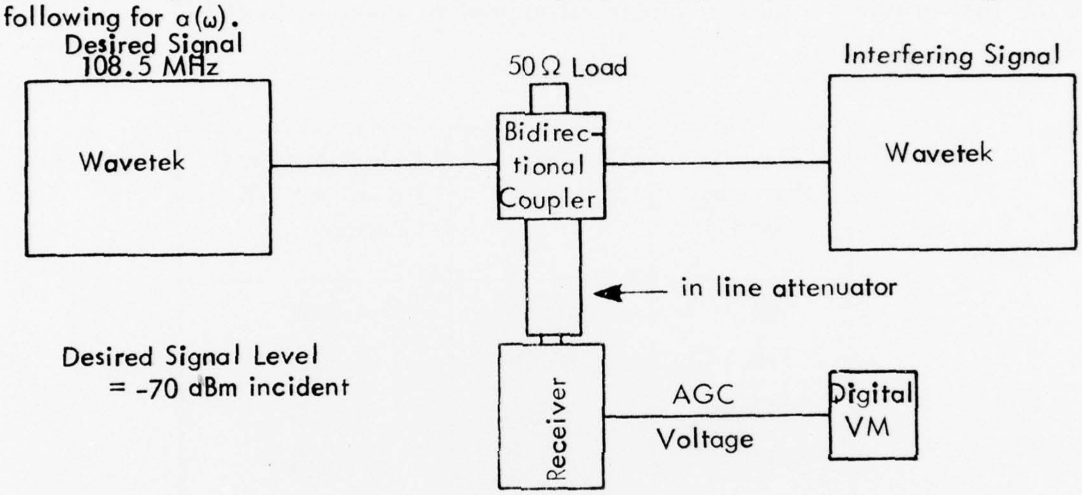


Figure B-3. Test Procedure for Determining $\alpha(\omega)$ Using Cross-Compression Methods.

Interfering Frequency MHz	Equivalent $\alpha(\omega)$ Calculated from Measured GC*	$\alpha(\omega)$ Found Probing RF Front End
107.5	- 1 dB	-1.2 dB
106.5	-3.1 dB	-2.7 dB
105.5	- 5 dB	-4.5 dB
104.5	-6.6 dB	-6.2 dB

*Gain Change

Table B-1. Comparison of Results Obtained Using Cross-Compression and RF Measurements.

Because cross-compression is a function of $\alpha^2(\omega)$ it was not possible to obtain enough interfering signal level with the above test procedure to measure 1 dB of GC for frequencies below 104.5 MHz.

2. <u>Measurements of Variations in $\alpha(\omega)$ as a Function of Receiver Tuning.</u> Investigations of the variations in $\alpha(\omega)$ as a function of frequency were made by tuning the receiver to different frequencies while keeping the interfering signal frequency at a fixed 3 MHz below the receiver frequency and measuring the resulting gain change (GC). The variations in $\alpha(\omega)$ with receiver tunings are given in Table B-2.

Receiver Frequency (MHz)	Interfering Frequency	Calculated $\alpha(\omega)$ Assuming K_3/K_1 Constant
108.5	105.5	-4.5 dB
110.5	107.5	-4.2 dB
112.5	109.5	-4.0 dB
114.5	111.5	-3.6 dB
116.5	113.5	-3.4 dB
117.5	114.5	-3.2 dB

Table B-2. Variations in $\alpha(\omega)$ as a Function of Receiver Frequency.

C. Interference Due to ELT

1. Introduction. There have been numerous reports where particular ELT's have been shown to aggravate the interference problem by reradiating signals generated by the nonlinear mixing in the ELT output transistor stage. It is believed that the transmitter (inactivated) output circuit acts as a diode mixer generating interfering signals in the localizer and communication bands, particularly in the communications frequency band (118-136 MHz).

The interference frequency is the result of a third-order nonlinearity term. For example, an interfering signal at 122 MHz can result from the mixing of two FM stations at 108 and 94 MHz ($2f_1 - f_2$) term, due to a third-order nonlinearity). It has also been reported that it is possible to observe enchancement of the interference problem due to the ELT as a result of the combining of an ILS, VOR and FM station. For example, an ILS frequency of 329 MHz, a VOR of 113.8 MHz and FM station at 94 MHz could mix producing an interfering signal at 121.2 MHz ($1 f_1 - f_2 - f_3$ term).

A third-order model has been investigated for modeling the effects of ELT in the interference problem. It was expected such a model would be adequate for predicting interference levels and because of its simplicity, it could be utilized effectively in practice. Figure C-1 illustrates the results obtained when two interfering signals are directly coupled into the ELT. The experimental procedure for obtaining these results is shown in Figure C-2. Figure C-1 illustrates the results obtained for various signal levels. The third-order term (102.5 MHz) clearly shows up in the spectral plots shown in this figure. In addition, it is observed that at extremely high signal levels + 5 dBm and above additional intermod terms appear (see Figures C-1 e,j,k and l) which would tend to indicate that a higher order model may be required.

Since the primary interest is in the analytical modeling of the ELT's role in the interference problem, it is necessary to be able to predict the signal levels coupled from the ELT antenna to the communications and/or navigational antennas. Measurements were obtained and a worst case theoretical analysis was performed.

2. ELT Model. A proposed analytical model representing the ELT is illustrated in Figure C-3a. Mathematically the model may be interpreted in two ways:

(1) The voltage e_a can be represented in terms of the received voltage by

$$e_a = k_1 e_i + k_2 e_i^2 + k_3 e_i^3 \tag{C-1}$$

(2) A second and somewhat more satisfying way to visualize the model is illustrated in Figure C-3b. In this representation the incident voltage v^+ is the received

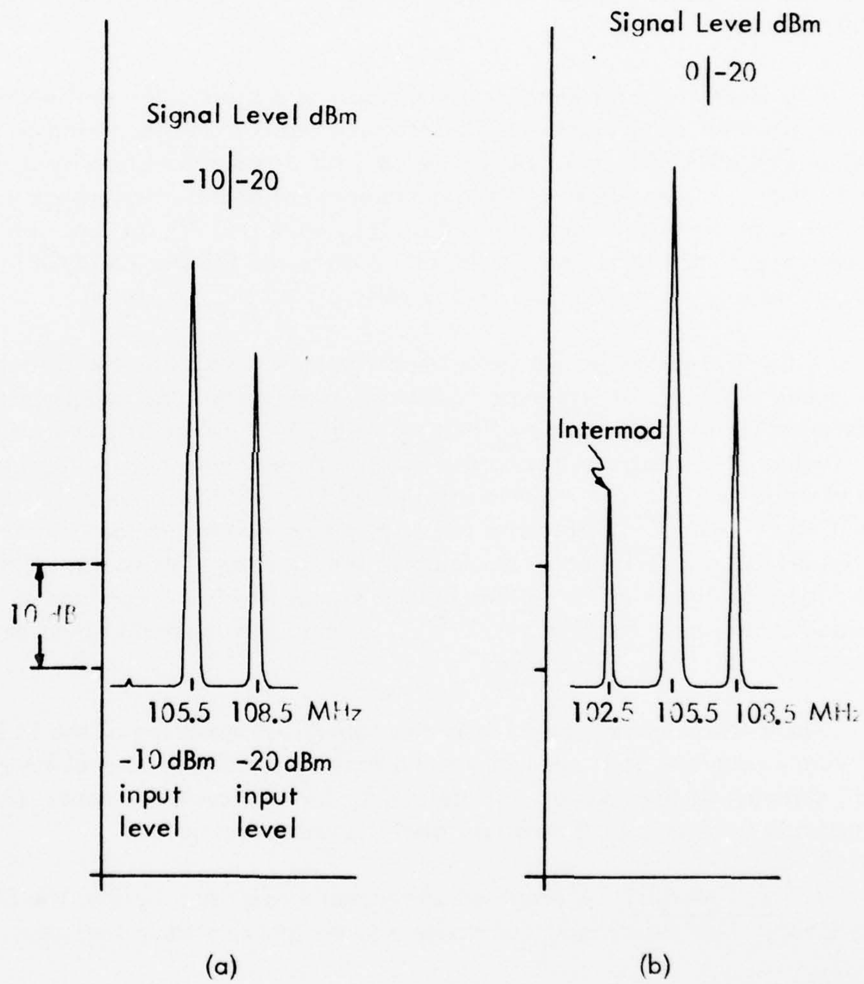
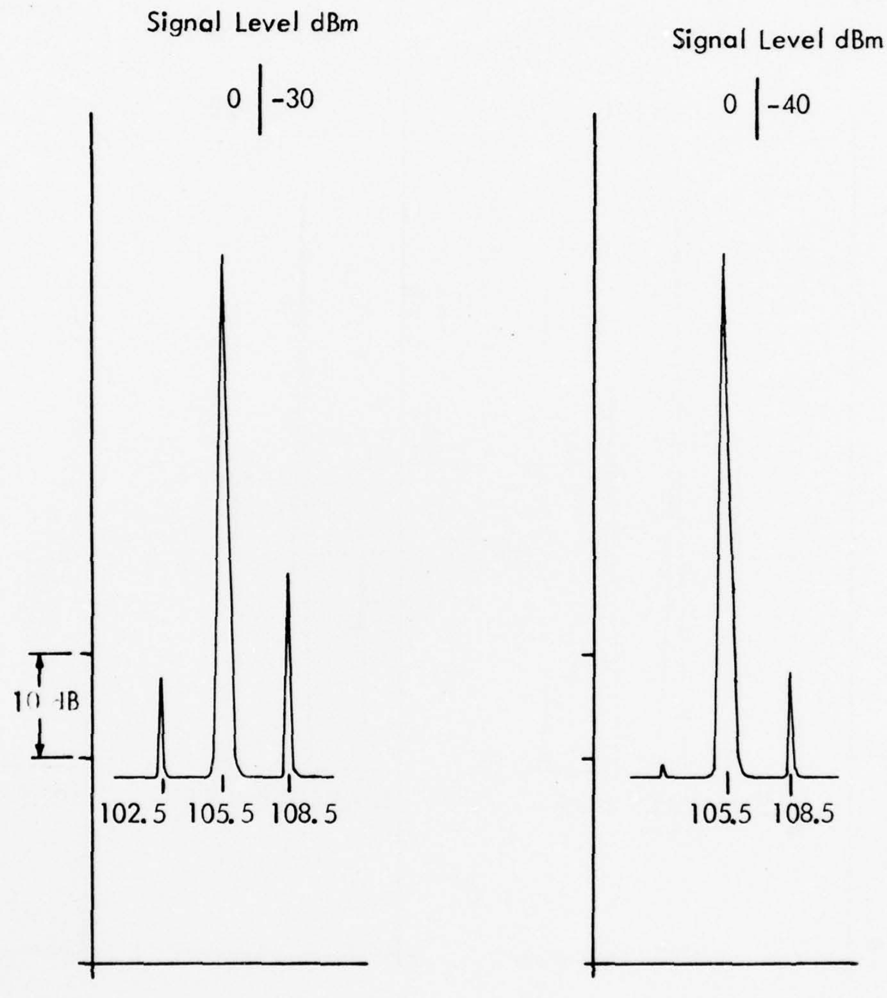


Figure C-1. Spectra of the Reradiated Signals at the Output of ELT. Vertical = 10 dB/1.5 cm; Horizontal scale = 2 MHz/cm.



(c) (d)

Figure C-1. Continued.

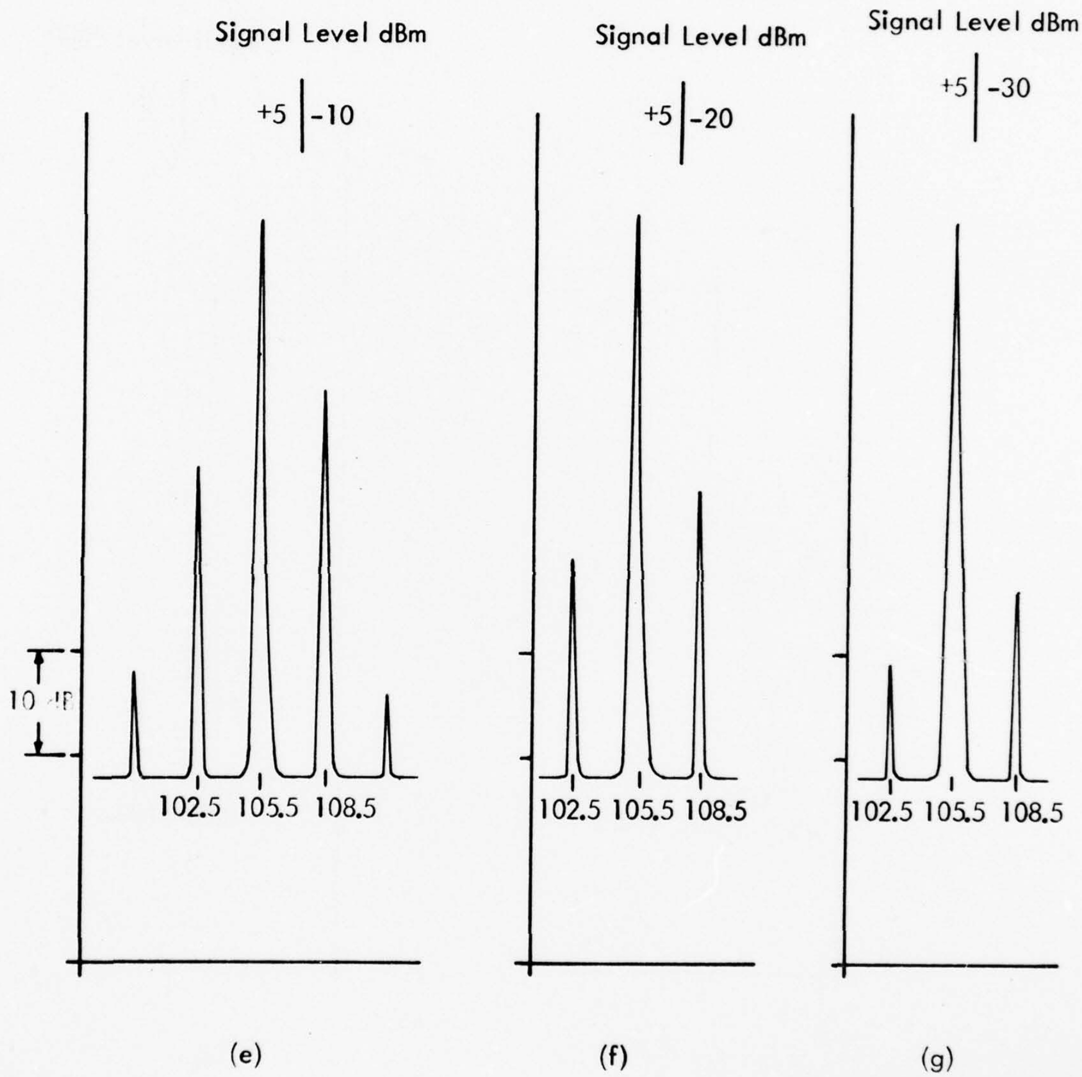


Figure C-1. Continued.

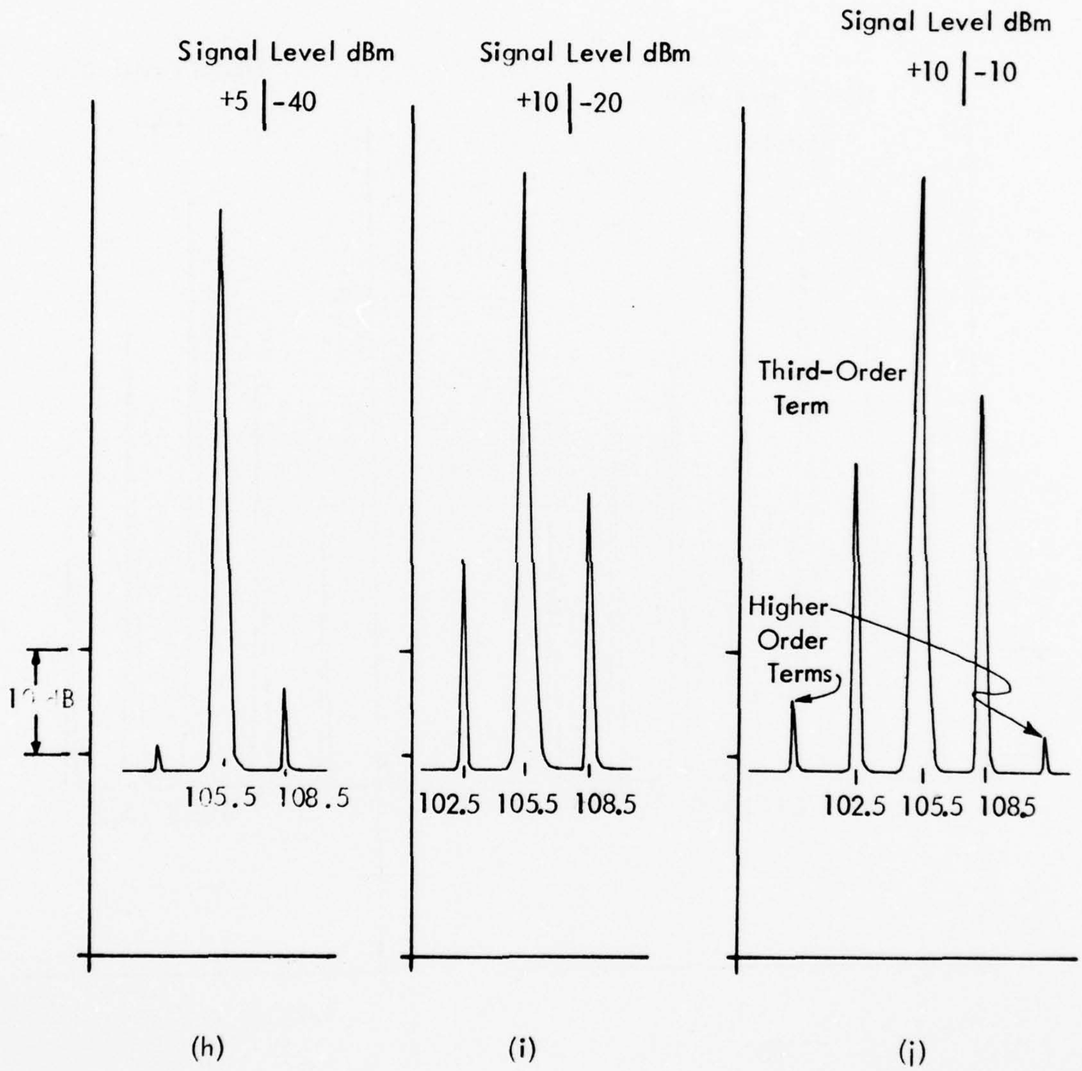


Figure C-1. Continued.

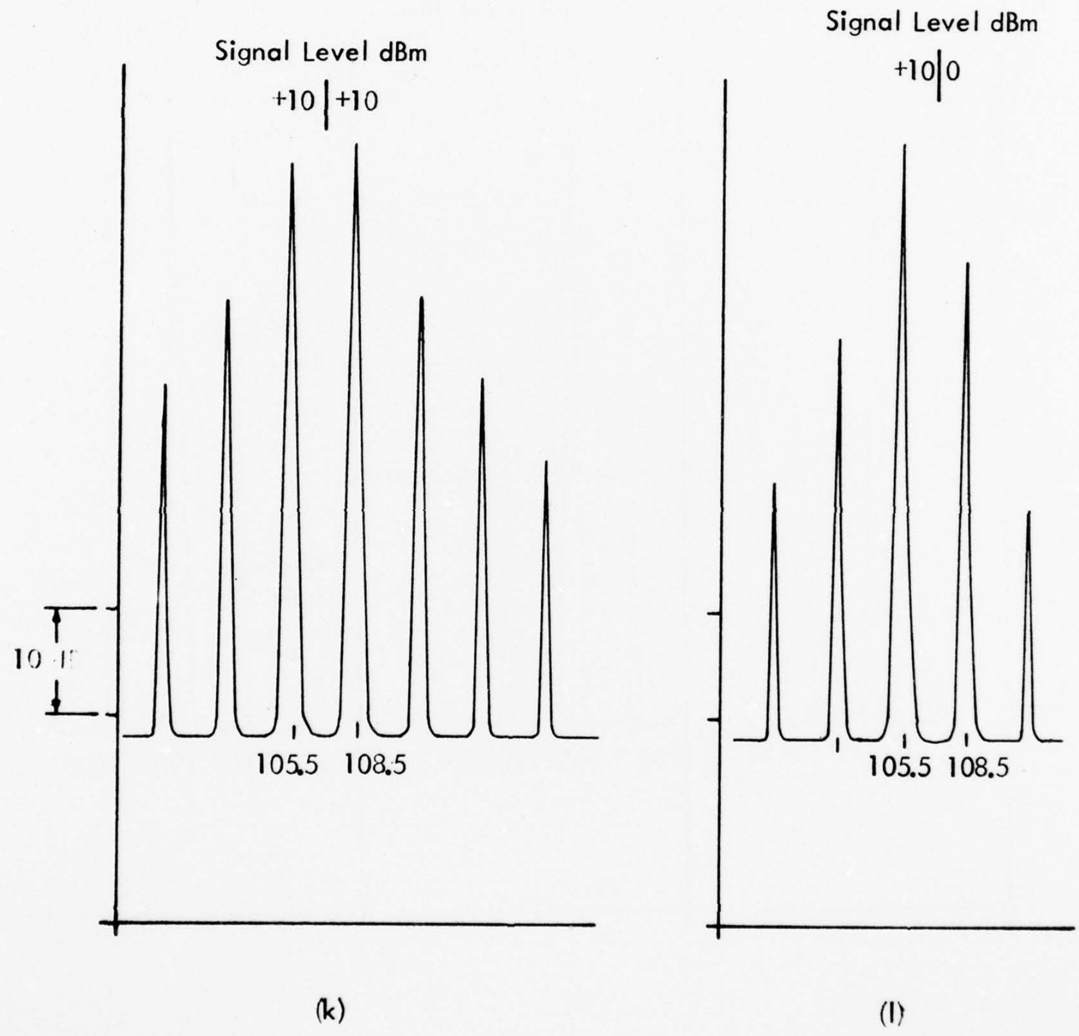


Figure C-1. Continued.

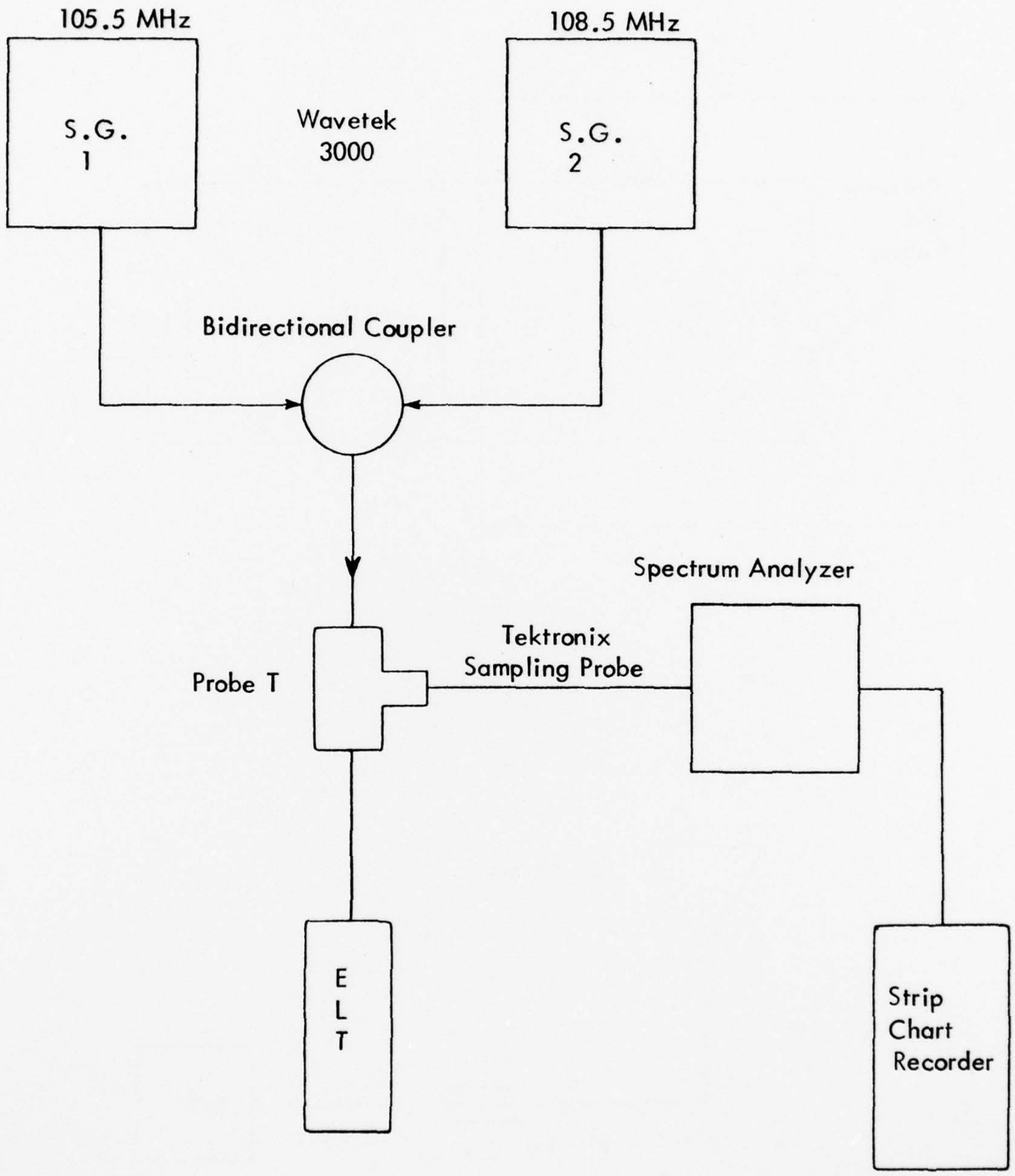
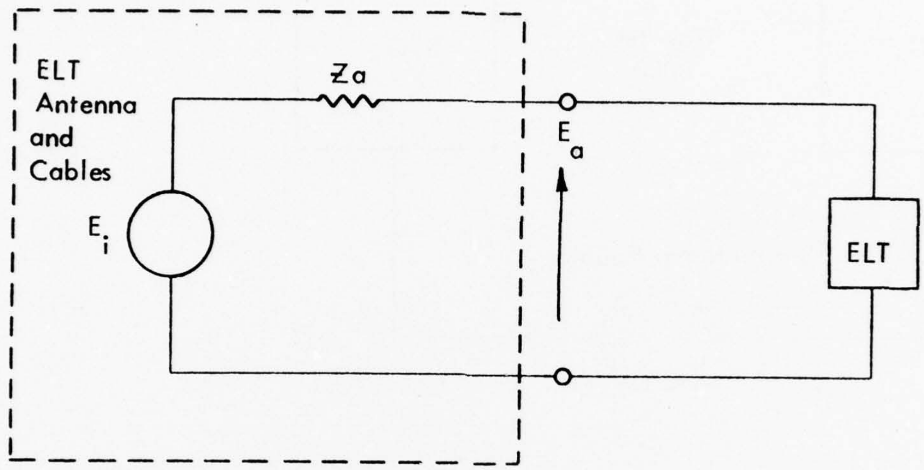
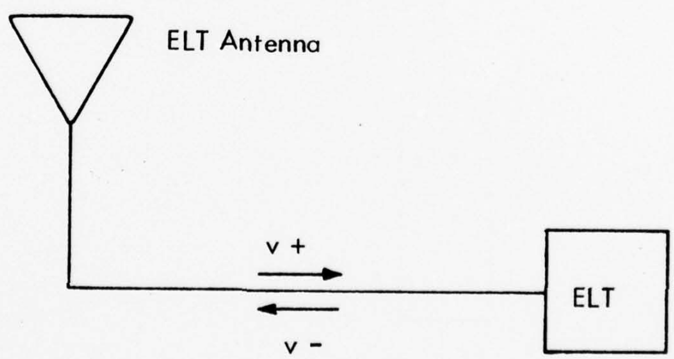


Figure C-2. Test Procedure for Spectral Measurements for Figure C-1.

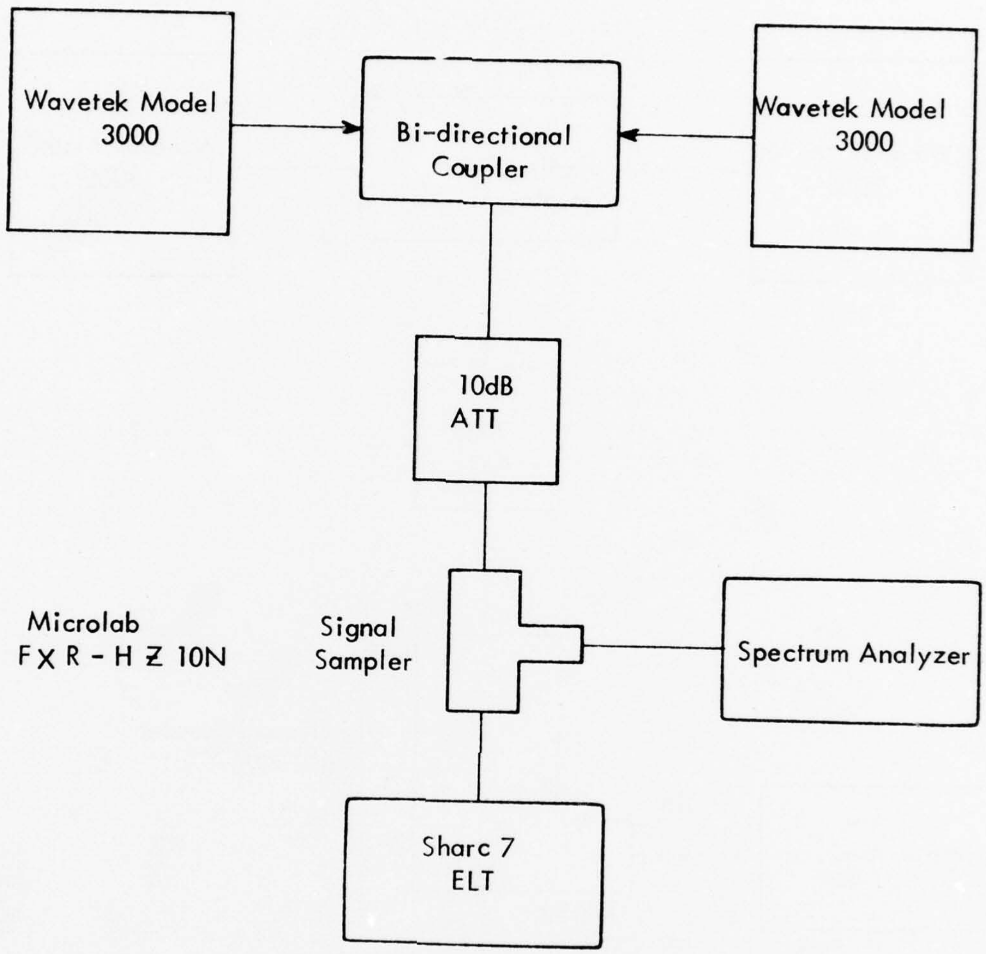


(a)



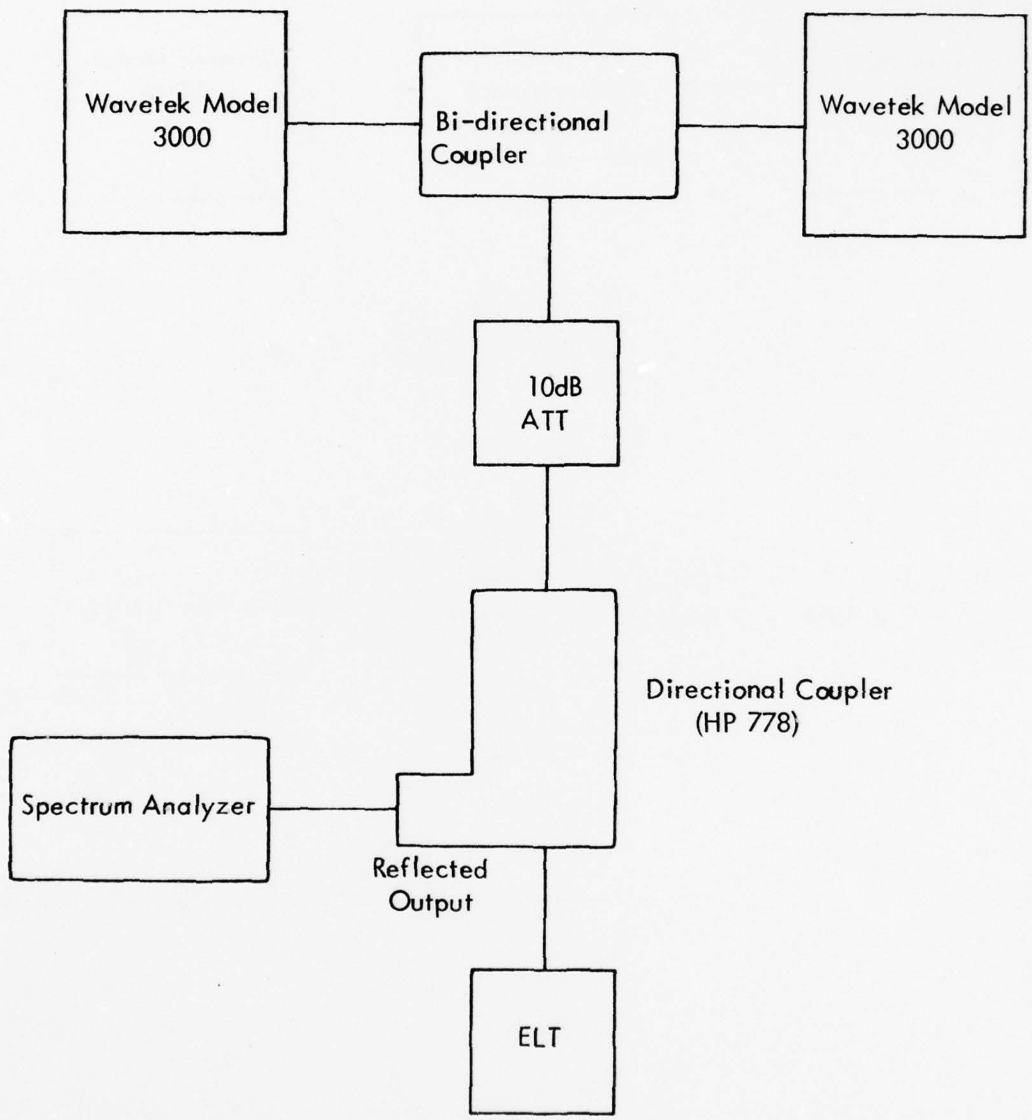
(b)

Figure C-3. ELT Model.



(a)

Figure C-4. Experimental Procedures.



(b)

Figure C-4. Continued

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ANALYTICAL DETERMINATION OF THE INTERFERENCE OF COMMERCIAL FM S--ETC(U)
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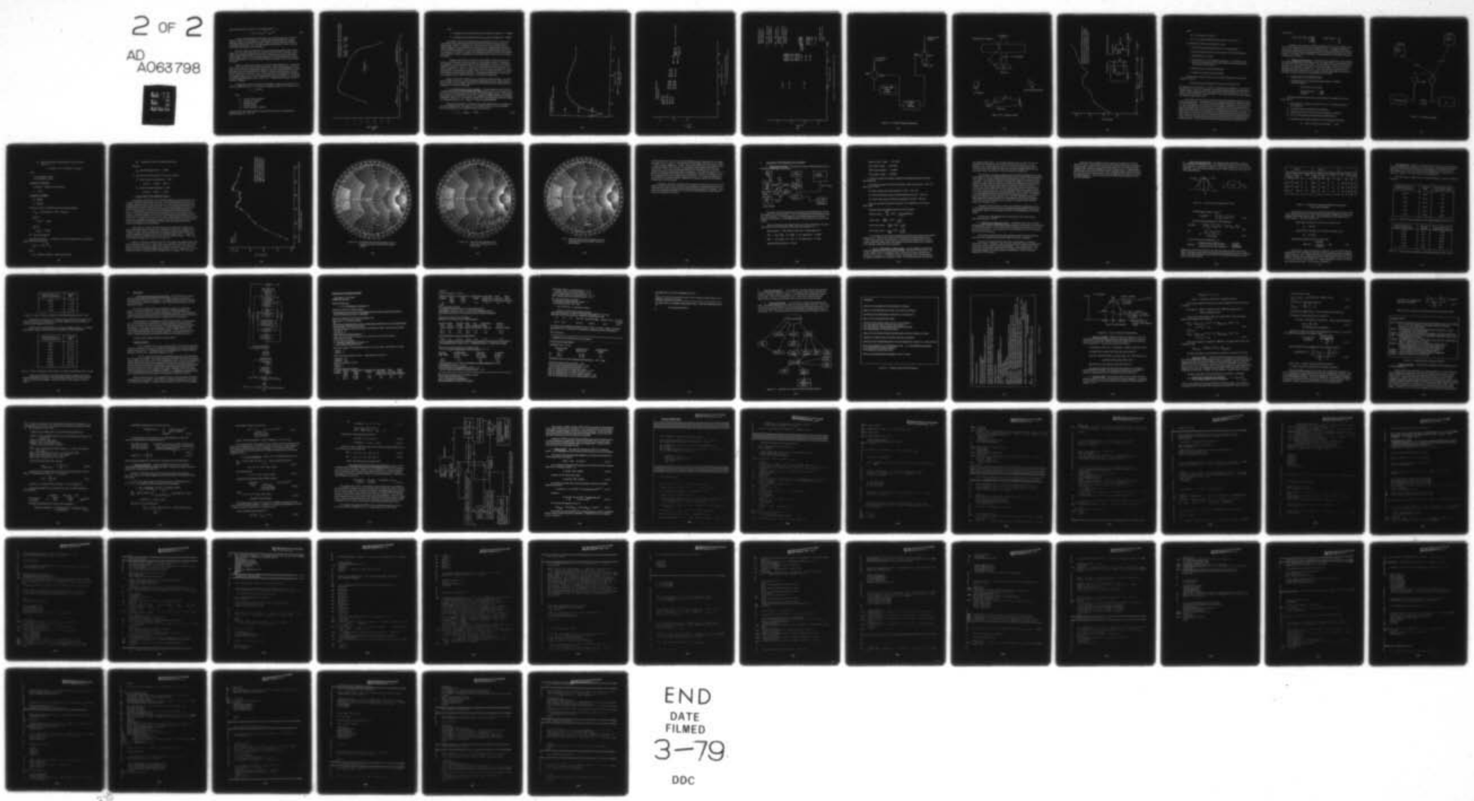

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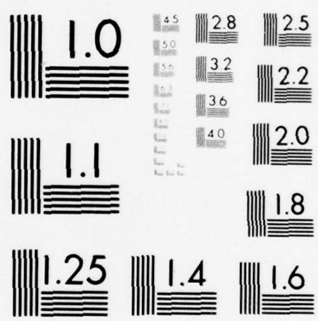

MICROCOPY RESOLUTION TEST CHART
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signal and the reflected voltage is the reradiated signal, i.e.,

$$v^- = k_1 (v^+) + k_2 (v^+)^2 + k_3 (v^+)^3 \qquad \text{(C-2)}$$

It can be shown that both of these models are essentially equivalent, the basic difference being in the interpretation. Neither model postulated takes into account frequency selective characteristics of the ELT output circuitry and both are limited to third-order nonlinearities. Also, the high frequency characteristics of the p-n junction are ignored in this preliminary investigation.

Using the models specified above the two experimental procedures illustrated in Figure C-4 were used to determine the parameter k_3 for the model. Although a considerable amount of data relating to self-and cross-compression was obtained, the primary important data is relative to the intermod frequency. In this section summary results are given in graphical form. The test procedure illustrated in Figure C-4a was used to obtain the results.

Figure C-5 illustrates the effects of two closely aligned frequencies. In particular this curve was obtained using two signals separated by 1 MHz and extending over the FM band. This curve tends to indicate that whenever two closely aligned frequencies interact the coefficient k_3 varies approximately $\pm$ 5 dB from a reference value arbitrarily chosen at the ELT frequency of 121.5 MHz. Some of these effects can be explained by considering the frequency characteristics of the ELT output stage which are in Figure C-6. In this the corrected voltage measured at the ELT input with a - 10 dBm incident signal is plotted as a function of frequency.

A rough approximation which ignores both frequency effects, (capacitance of the junction), signal levels, etc., is to use the low frequency model of the p-n junction, i.e.,

$$i = I_o \left(e^{qv/kT} - 1 \right)$$

where

I_o = reverse current in amperes
k = Boltzmann's constant
T = temperature in °k
v = applied voltage
q = electron charge in coulombs

Using this model would imply that the intermod term would have an amplitude given approximately by (A + 2 B + 15)

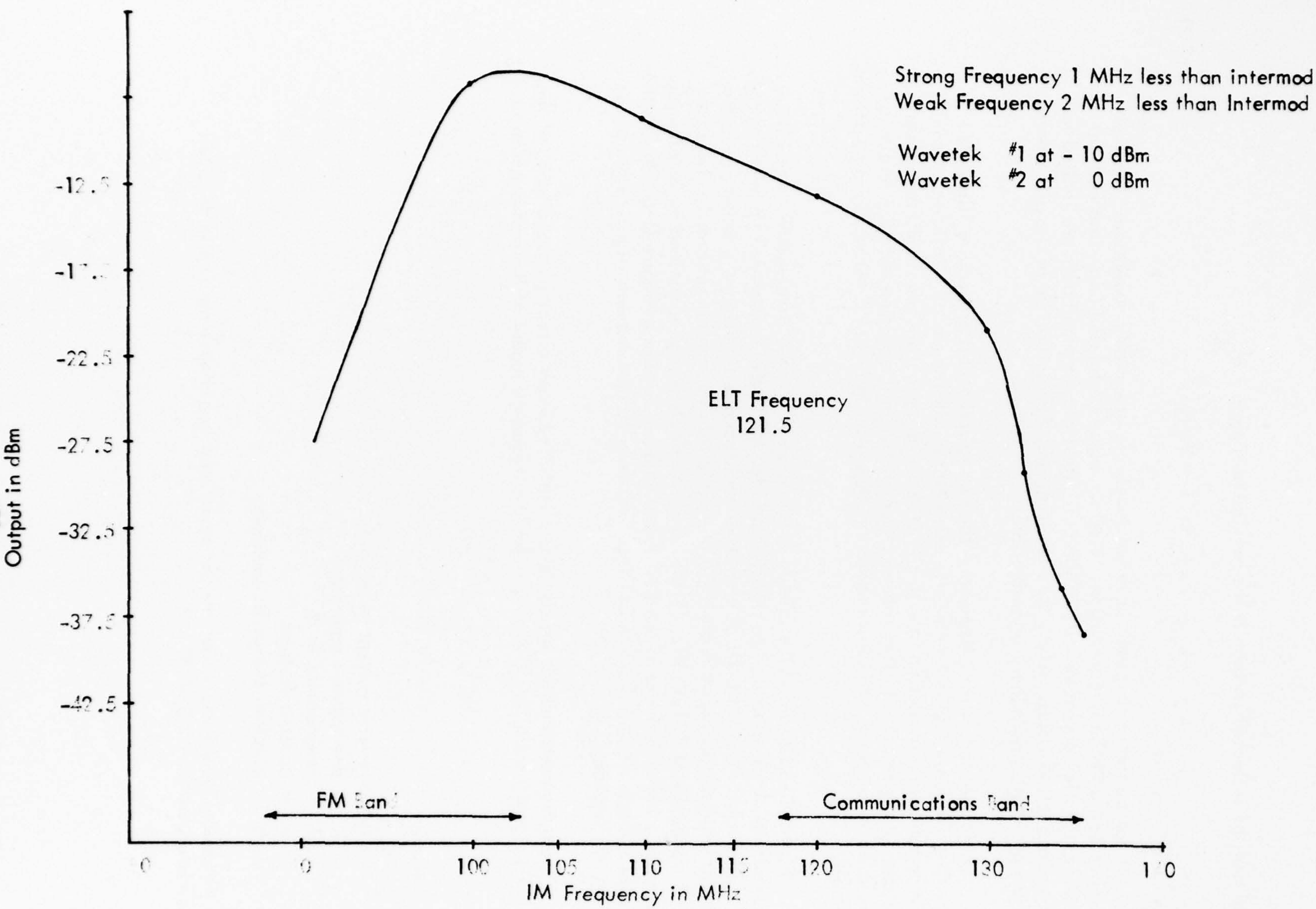


Figure C-5. IM Effects of Two Closely Aligned Frequencies.

where

A = amplitude of the weak signal (for the case shown in Figure C-6 = -10 dBm)

B = amplitude of the strong signal (for the case shown in Figure C-6 = 0 dBm)

The 15 dBm is the result of expanding the exponential in a series. For the case considered here this would imply that the intermod term would have an amplitude of approximately -25 dBm. Using Figure C-5 this result seems to be reasonable when the intermod frequency is approximately 121.5 MHz; however, it deviates somewhat from this value for different frequencies. It must be stressed that the equation used to describe the p-n junction is by no means accurate at these frequencies; however, bounds on the problem can be obtained. Further investigations are required in order to arrive at a more accurate description.

A large amount of data was obtained which tended to indicate that the coefficient k_3 can be assumed relatively constant over wide frequency ranges. Although the data obtained is too numerous for inclusion in this brief report, a summary of the results is illustrated in Figures C-7 and C-8. The data was obtained using the test procedure illustrated in Figure C-4a. Figure C-7 indicates the variation in k_3 as a function of the intermod frequency as indicated on the graphs. These curves were obtained with the two signals held constant at -10 and 0 dBm respectively. These results indicate that the coefficient k_3 is constant within ± 5 dB of the value at 121.5 MHz (ELT frequency).

Figure C-8 shows the variation in k_3 as a function of signal amplitude. For signal levels of 0 dBm and below, k_3 can be bounded by approximately ± 5 dB. Results indicate that k_3 deviates more for signals with frequencies in the lower part of the FM band than for frequencies in the middle of the band.

3. ELT Communications Antenna Coupling. In order to determine the effects on communication receivers of an intermod signal reradiated by the ELT, it is necessary to have some measure of the coupling between the ELT and communications antennas. Experimental measurements were performed on a Cessna 150 commuter (N1600U) using the test procedure illustrated in Figure C-9. The relative locations of the communications and the ELT antenna are illustrated in Figure C-10. Figure C-11 shows the results obtained.

Although the mathematical calculations for aircraft antennas are very complex and can only be approximated very crudely, it is of interest to achieve a worst case model. The relations between a set of coupled antennas can be given by

$$v_i = \sum_{j=1}^{n} (Z_{ij}) I_j \quad i = 1 \text{ to } n \tag{C-3}$$

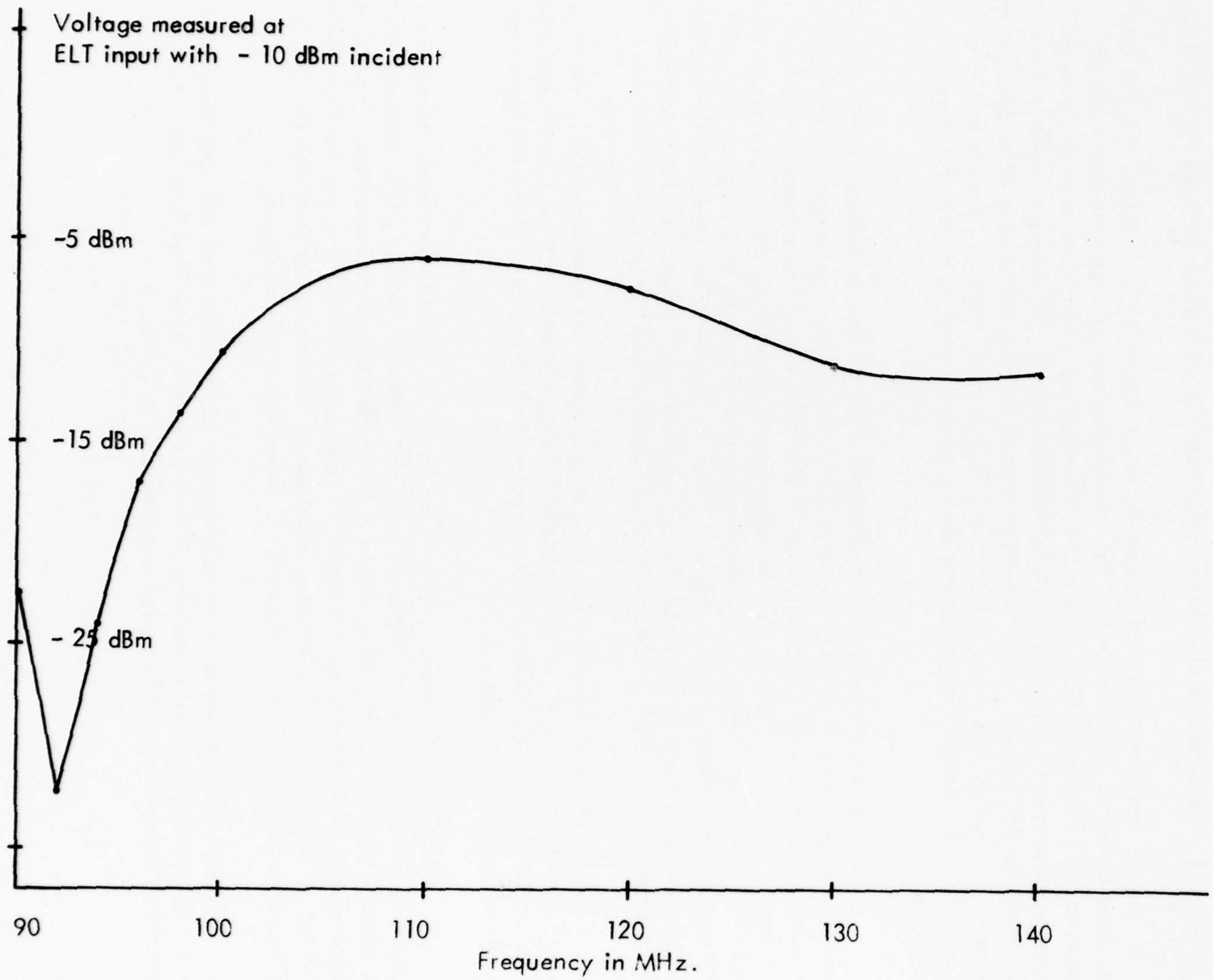


Figure C-6. ELT output voltage as a function of input frequency.

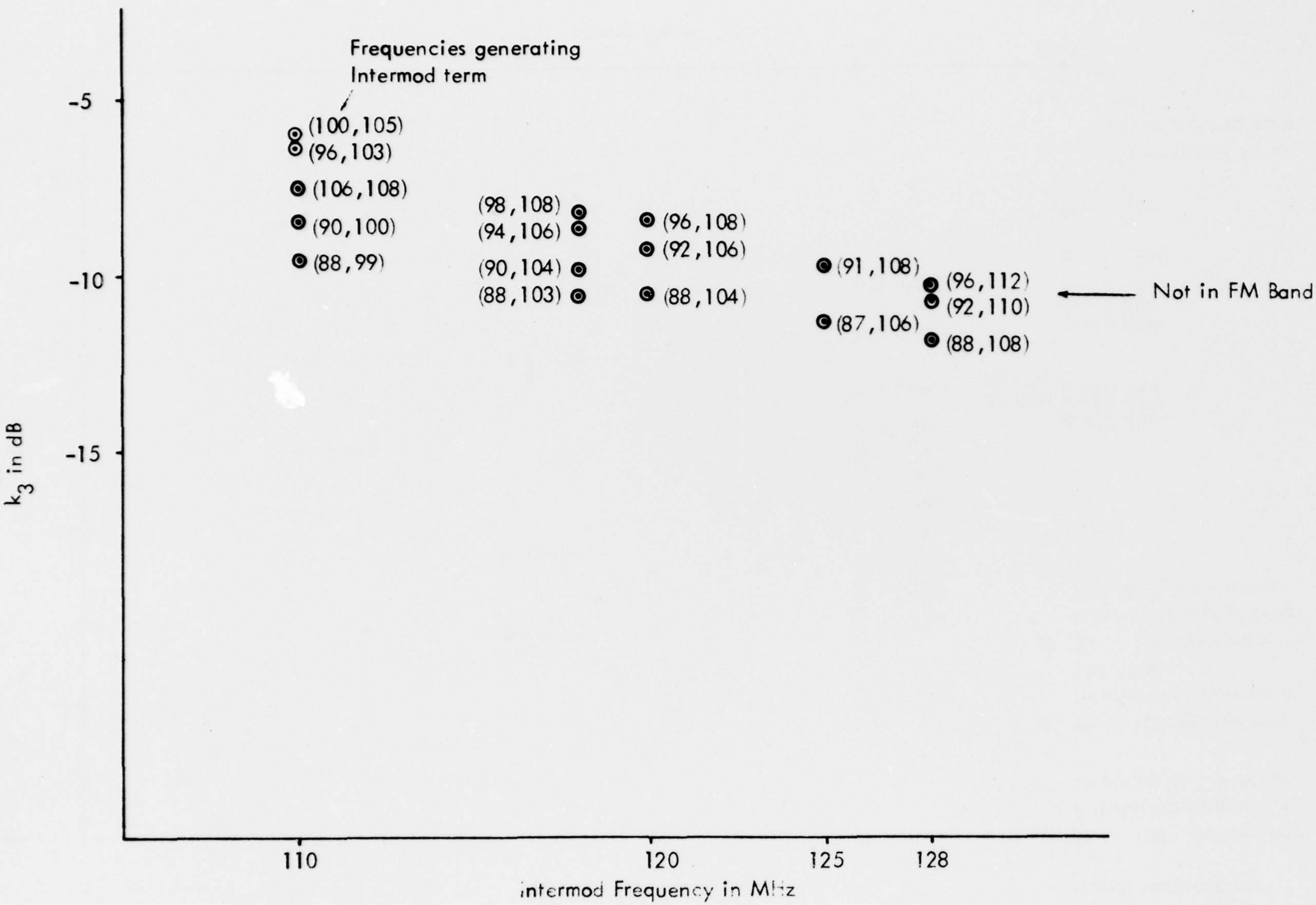


Figure C-7. k_3 as a function of intermod frequency for varying FM band generating frequencies.

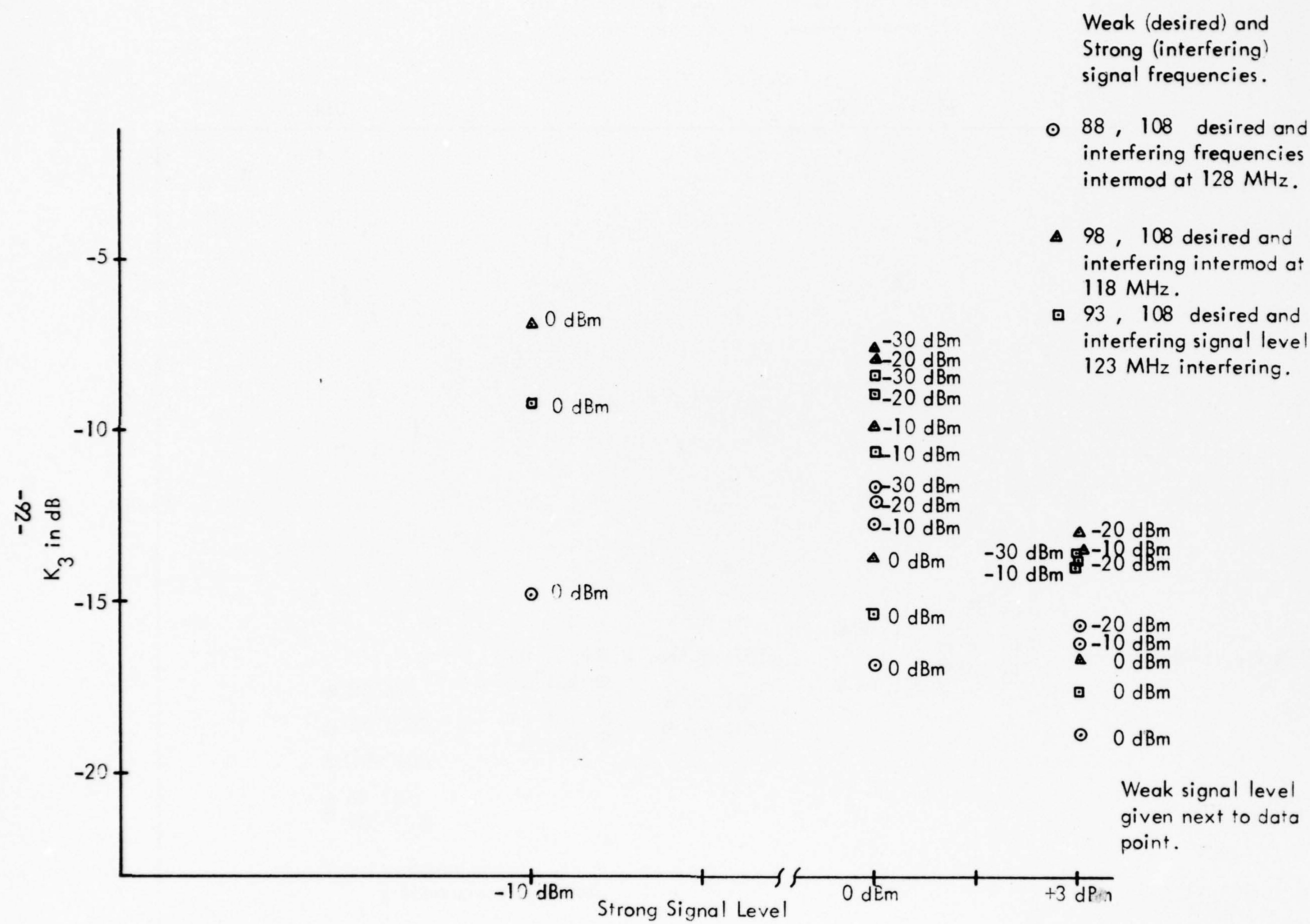


Figure C-8. Variation of k_3 for Different Signal Levels.

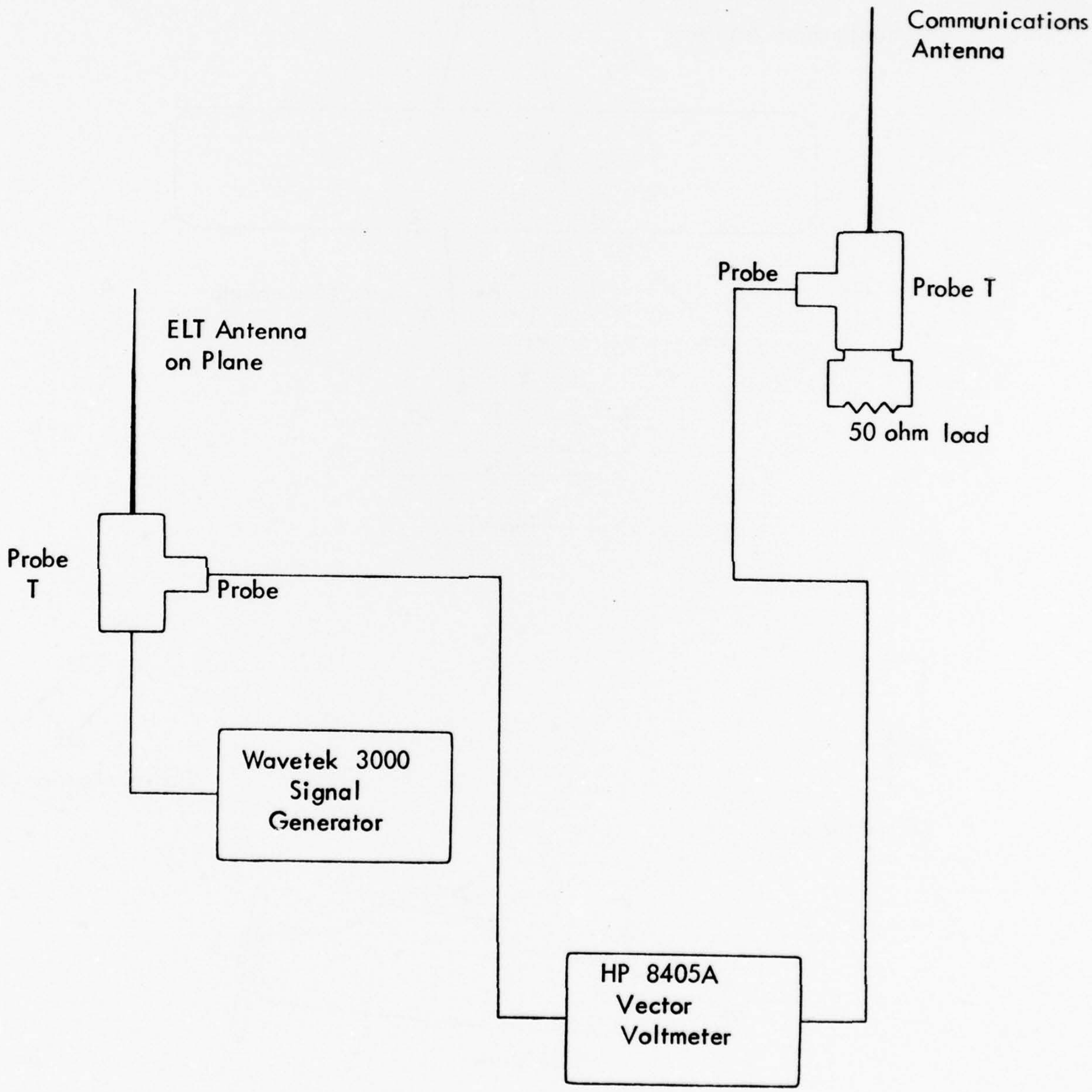


Figure C-9. Antenna Coupling Measurement.

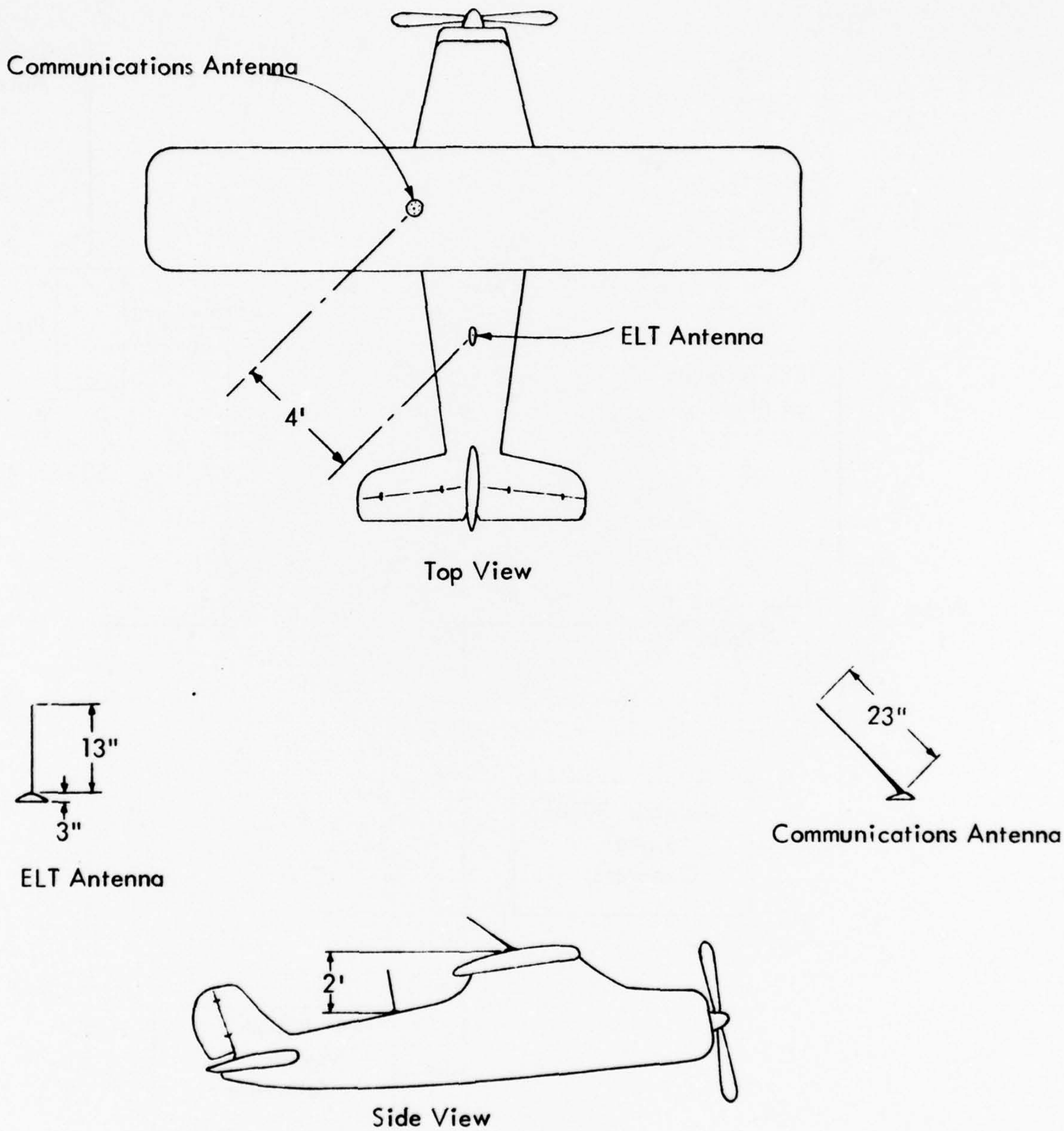


Figure C-10. Antenna Locations.

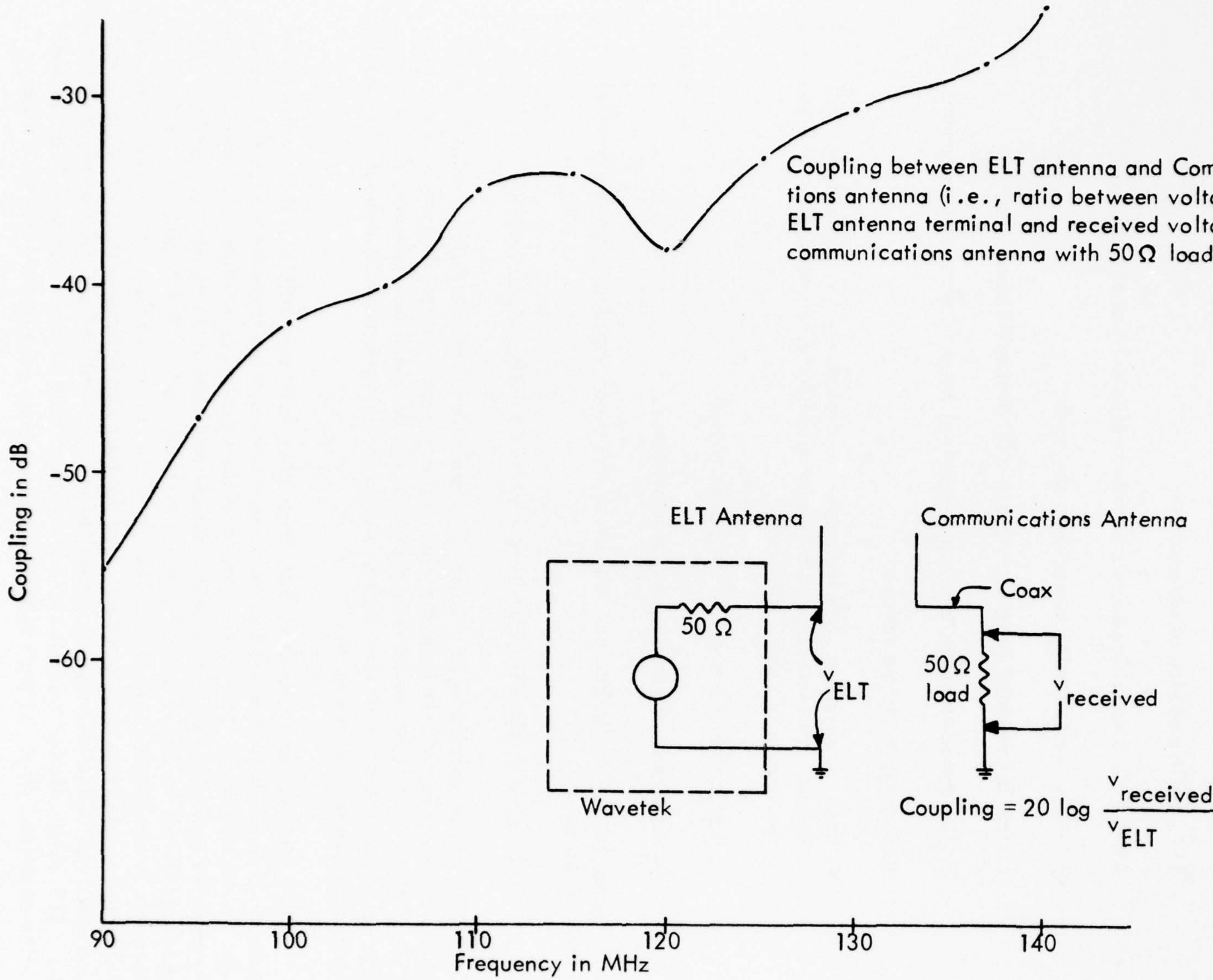


Figure C-11. ELT - Communication Antenna Coupling.

where

Zii = self impedance of antenna i

$Zij = Zji$ = mutual impedance between antenna i and antenna j.

For simplicity the following assumptions are made:

1. The ELT antenna (transmitting) has a 50 ohm self-impedance.

2. The communications antenna (receiving) has a 50 ohm self-impedance.

3. Both antennas are matched.

4. Both antennas are $\lambda/4$ monopoles separated by $\lambda/2$ (actually the ELT antenna was measured to be 16 inches and the communication antenna was measured to be 23 inches).

5. Both antennas have infinite ground planes.

6. Antennas are parallel and on same plane.

Using the above relations and the curves of mutual impedance for two parallel antennas as given in

"Antenna Engineering Handbook" by Henry Jasik, McGraw-Hill,

the coupling can be calculated as - 16 dB, a considerably more pessimistic value than the measured value. Figure C-11 indicates the maximum measured coupling was approximately -28 dB. Further investigations for refining this model are required; however, the calculations could be considered a worst case analysis. For a more realistic value of the coupling, the measured values could be used.

ELT's used on many Cessna aircraft seem to be more susceptible to third-order intermodulation phenomenon. Reportedly, the Cessna Company has partially solved this problem by certain modifications. Mr. Gordon Wood of the Cessna Corporation in Wichita, Kansas, was contacted regarding this and he said that the problems of interference are greatly reduced (to tolerable levels) if the ELT antenna is shortened from the original 22" to 16" and adjustments in the output stage and cabling for matching and maximum power are made. The effect of this would seem to be a reduction in the coupling between the ELT and communication antennas. Ohio University has available several small aircraft instrumented with the Sharc 7 ELT which allowed practical measurements on both aircraft with modified and non-modified antennas. These aircraft along with the antenna lengths are listed as follows

for reference:

Cessna 150 Commuter	N1600U	Antenna Length = 16"
" " "	N 900U	" " = 16"
" " "	N 1200U	" " = 22"

In addition to the decrease in antenna length from 22" to 16", the locations of the 22" and 16" antennas on the aircraft were slightly different. Although no evidence is present which would indicate this to be a significant factor, it is possible that the location was moved so as to decrease the coupling between the communications antenna and the ELT antenna. It is unlikely that the reduction in coupling obtained is totally due to decreasing the length of the antenna.

4. Summary and Applications. In summary and as an illustration of the techniques and models developed here a worst case analysis (very approximate) is given illustrating the role of the ELT in the interference problem. For the example, two 100 kw FM stations are assumed - one located 15 miles from the receiver and the other 5 miles from the receiver. The geometry is illustrated in Figure C-12. Only the interference caused by the ELT generated intermod is considered in this example. Using the information and data given in this report, the following step-by-step computations can be made:

a. Aircraft with 16" ELT Modified Antenna

I. Coupling between ELT and communications antennas at 120 MHz (intermod frequency)

From Section 3 of this report

Theory (worst case) = - 16dB
Measured = - 35dB

The large discrepancy between theory and measurement is probably due to many factors such as:

1) The modified ELT antenna of length 16" is not a $\lambda/4$ antenna as assumed in the calcuations.
2) The possible location change of the ELT antenna.
3) Communications and ELT antennas not being parallel, as assumed.
4) ELT and communications antennas being in different planes.

II. Calculation of the incident voltage at the ELT assuming the following:

(a) Directive gain of the ELT antenna $\cong$ 6 dB

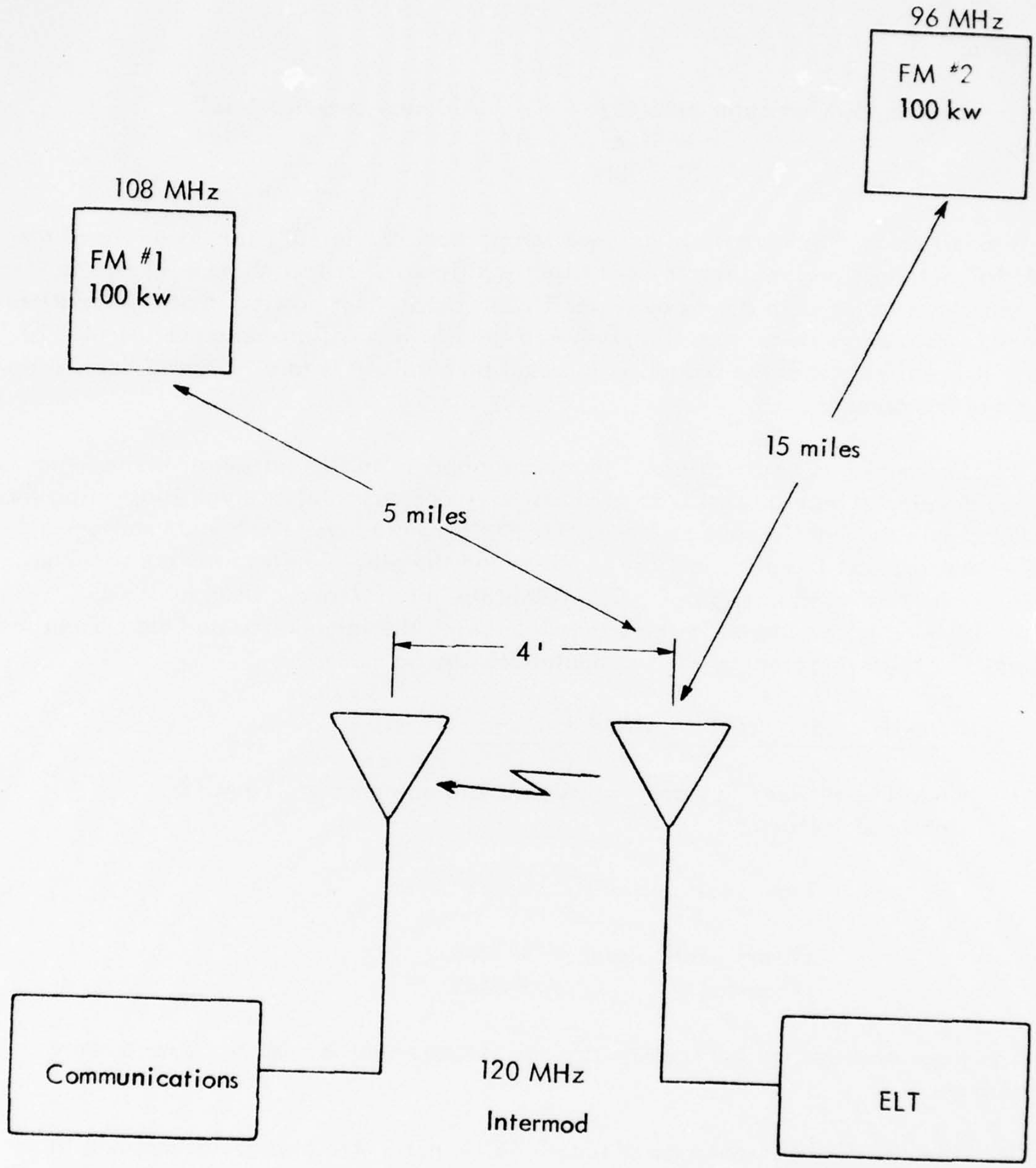


Figure C-12. Interference Model.

(b) Attenuation equation between lossless isotropic antenna holds, i.e.,

$$\alpha \text{ (decibels)} = 36.3 + 20 \log_{10} f + 20 \log_{10} d$$

where

f is the frequency in MHz
d is the distance in miles

FM station #1 (108 MHz)

P_1 (power) = 80 dBm (50 ohm reference)

$\alpha_1 = 91$ dB

FM station # 2 (96MHz)

$P_2 = 80$ dBm

$\alpha_2 = 100$ dB

The power at the ELT is obtained using the following equation:

P'_{ELT} = gain (antenna) + ERP - attenuation

FM # 1

P'_1 (ELT) = -5 dBm

FM #2

P'_2 ELT = -14 dBm

III. Intermod Calculation:

Using the value of $\frac{3}{2} k_3 = -8$ dB given in this report (Figure C-8), the reradiated signal from the ELT is given by

$$R_{ELT} = A + 2B + \frac{3}{2} k_3$$

where

(A) = amplitude of station 1 (weak station) in dBm

(B) = Amplitude of station 2 (strong station) in dBm

Therefore,

R_{ELT} (reradiated signal power) = - 32 dBm

IV. Calculation of intermod input at the receiver terminals.

(1) Using the worst case coupling of - 16 dB

Intermod = - 48 dBm ($\approx$ 900 μv)

(2) Using the measured coupling of - 35 dB

Intermod = - 67 dBm ($\approx$ 100μv)

b. Aircraft with 22" (Non-Modified) Antenna.

Investigations and inquiries as to the possible modifications of the calculation procedures to include the effect above were made. These findings indicate that numerical procedures should be possible which would allow for a more accurate specification of the coupling between antennas located on aircraft. Such an undertaking is beyond the work defined under the current contract and would consist of a rather significant program in itself. It would appear in view of the increased possibilities of interaction between electronic devices on board aircraft (one example being the ELT and communications antennas), it would be beneficial for the FAA to consider supporting investigations in these areas either as an extension of the scope of the current study or possibly an additional project in the future. Although neither time nor funds have been allocated on the current contract for these investigations, the analytical techniques which have been determined are believed to indicate worst case conditions.

Results given in Section A indicate theoretically a coupling of -16 dB between the ELT and communications antennas, while measured values for 16" ELT antenna gives a coupling of -35 dB. Further measurements were made on aircraft Cessna N1200U, 150 commuter equipped with a Sharc 7 ELT and a non-modified antenna of 22" in length and another aircraft Cessna N900U, Commuter 150, with the modified antenna. These results are summarized in Figures C-13, C-14, C-15, and C-16.

Figure C-13 shows the coupling between the ELT antenna (non-modified length -22") and the communication receiver. These results were obtained by exciting the ELT antenna and measuring the voltage at the output of the communications receiver. The results of Figure C-13 indicate a measured coupling approximately -16.5 dB. Comparing this with the calculated value of -16 dB given above, the agreement is very good. This is the result

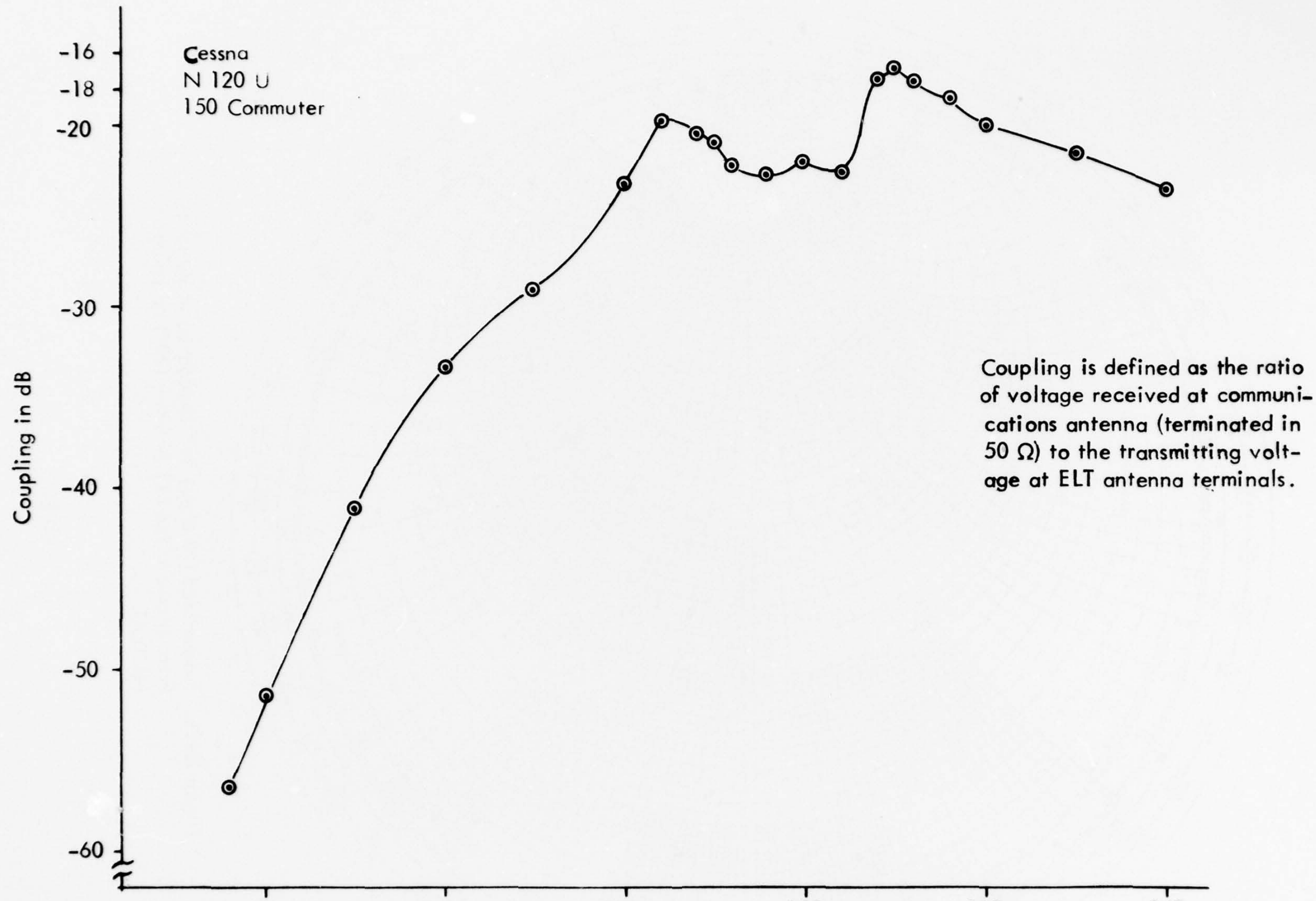


Figure C-13. Coupling Between ELT Antenna and Communication Antenna as a Function of Frequency
22" ELT Antenna Length.

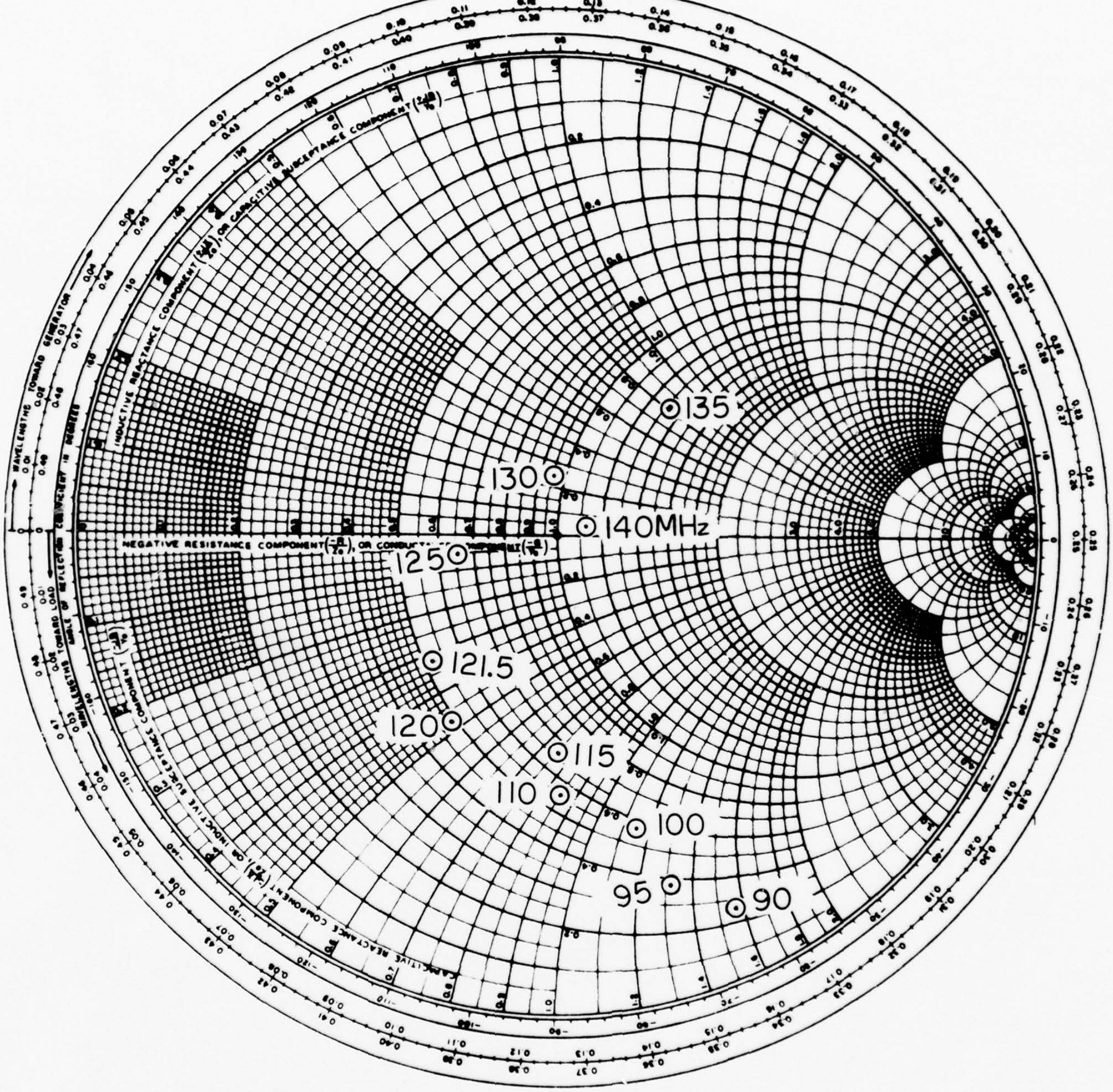


Figure C-14. Normalized (50 ohms) Self Impedance at Various Frequencies of the ELT Antenna (22") on Board N1200U.

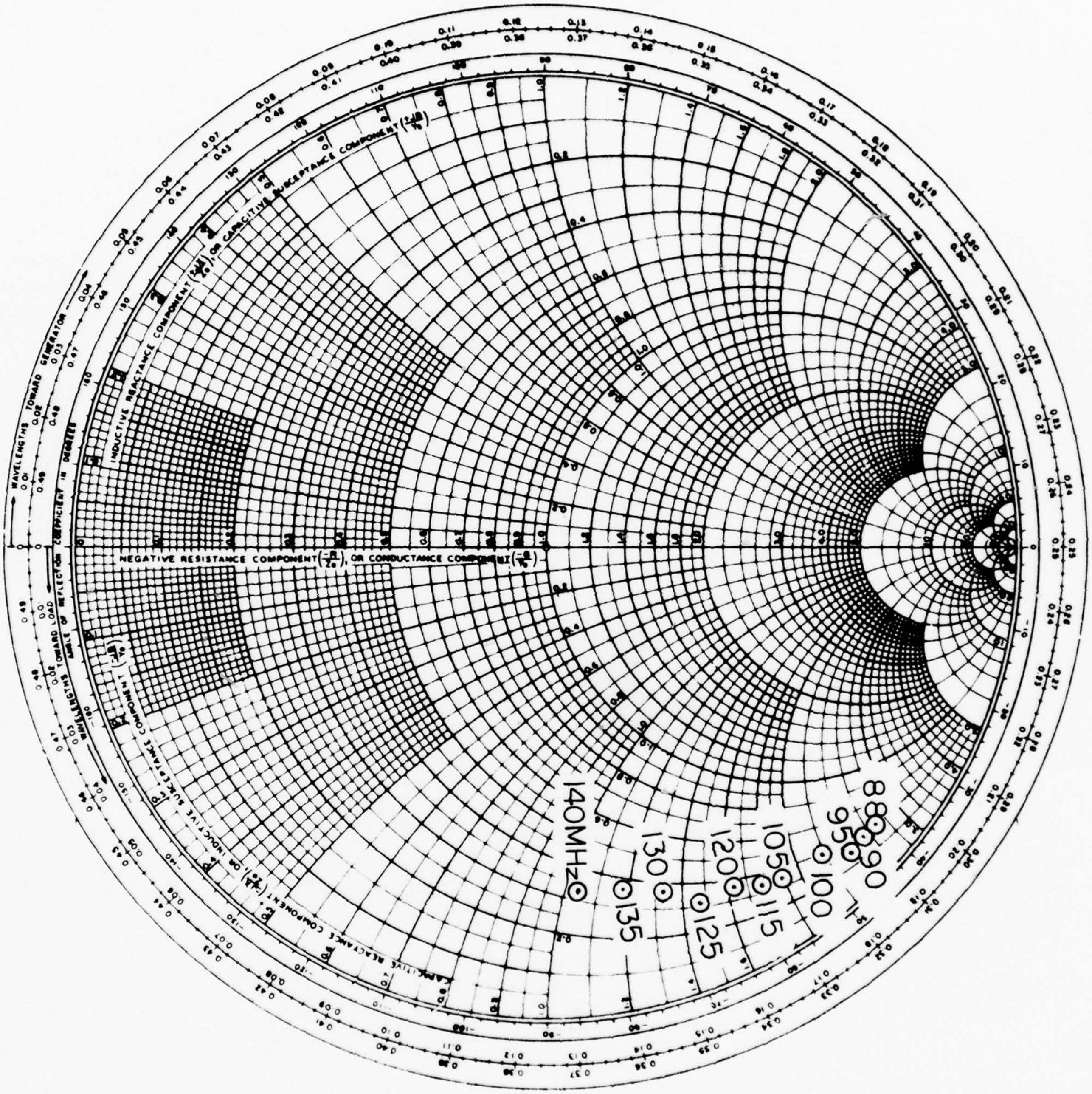
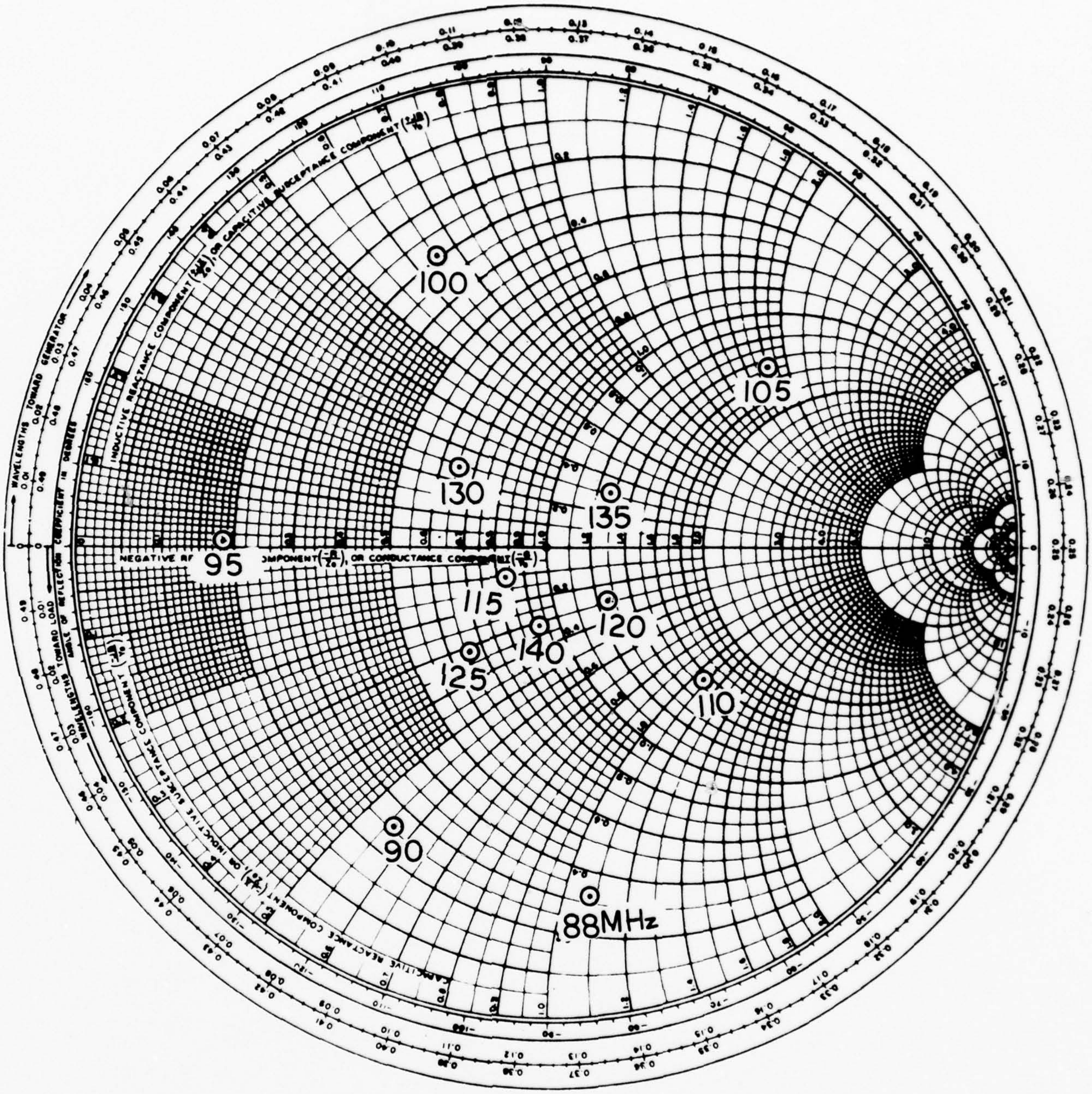


Figure C-15. Normalized Self-Impedance of ELT Antenna (16" Modified Antenna) on Board N900U.



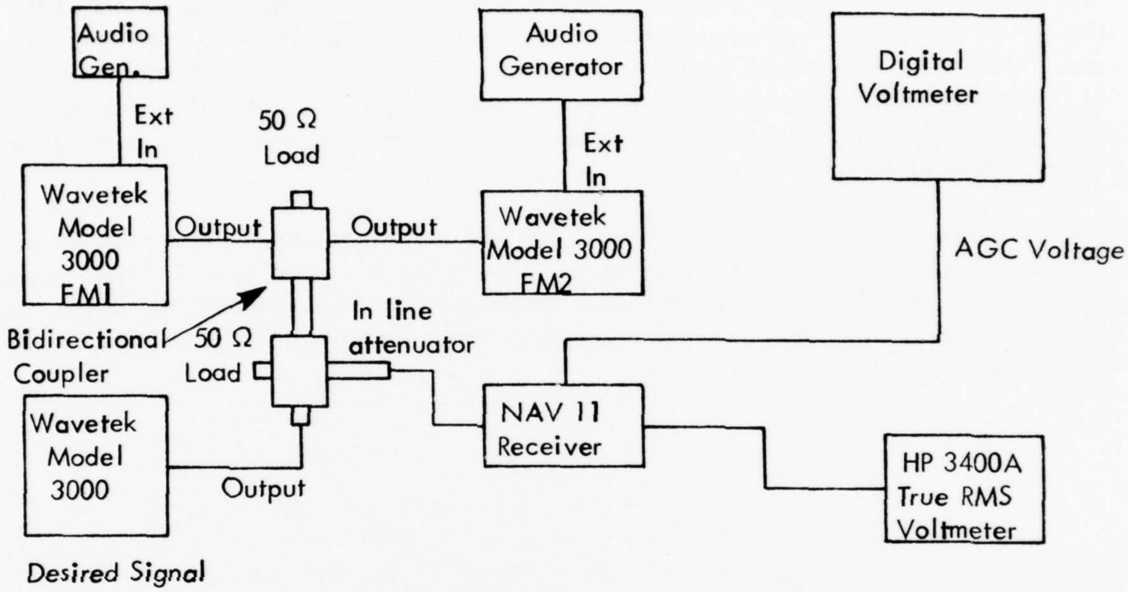
C-16. Normalized (50 ohms) Self Impedance at Various Frequencies of the Communications Antenna on Board N1200U.

of the geometry of the ELT system on board N1200U being more representative of the worst case system used in Section A. The calculated intermod input at the receiver was - 48 dBm (≈ 900 μv) using a coupling of - 16 dB. Such a level would result in an extremely severe interference problem which would be of considerably more importance than either the "brute-force" or the normal intermod (generated by the interaction of two or more FM stations of appropriate frequencies) types of interference. For reference Figures C-14, C-15, and C-16 are included which indicate the self-impedance of the 22" ELT antenna the 16" ELT antenna and the communications antenna respectively. It is noted that impedance of the modified 16" antenna is somewhat independent of frequency and far from the assumed 50 ohms used in the calculations.

In summary, results have indicated that the analytical model agrees with the 22" ELT antenna measured results rather well and may be considered a worst case situation; however, it does not agree with the measured values obtained using the modified ELT antenna. Since this was not a specific delineated task on this contract investigations for refining the ELT model were suspended at this point.

D. Measurement of RMS Modulation Due to Intermod

1. **Measurement Technique**. To measure the amount of RMS modulation due to intermod the following set up was used:



The outputs of three RF generators are combined through bidirectional couplers and inputted to the NAV 11 receiver. Two of the generators are FM modulated by audio sine-wave generators. The other generator is the desired signal tuned to the same frequency as the receiver. A true RMS voltmeter is used to measure the receiver filter outputs.

Using two FM signals with characteristics given below the detector, the audio filter output, the 90 Hz and 150 Hz filter outputs are measured, i.e.,

Desired Signal: f = 108.5 MHz, Carrier only, -60 dbm signal level

FM1: f = 102.5 MHz, fm = 400Hz, $\beta = 30$, signal level = -18 dbm

FM2: f = 105.5 MHz, fm = 1 KHz, $\beta = 20$, signal level = -17 dbm.

Measured IM Carrier level = -70 dbm.

Detector output voltage = .155 VRMS

Audio output voltage = .305 VRMS

150 Hz output voltage = .11 VRMS

90 Hz output voltage = .10 VRMS

In order to compute the necessary constants the following normalizing constants were determined:

(1) Detector voltage with 20% AM modulation output was measured as .250 volts volts with fm = 20 Hz

(2) Audio voltage with 10% modulation at 1 KHz = .665 volts

(3) 90 Hz filter output voltage with 20% modulation at 95 Hz = .891 volts

(4) 150 Hz filter output with 20% AM modulation at 145 Hz =.999 volts

Using the normalizing constants calculations of % modulation can be made as shown below:

Calculating Equivalent RMS Modulation of Filter Outputs

$$\text{Detector output} = \frac{.155}{.250} \times 20\% = \underline{\underline{12.1\%}} \text{ modulation}$$

$$\text{Audio output} = \frac{.305}{.652} \times 10\% = \underline{\underline{4.7\%}}$$

$$\text{150 Hz filter output} = \frac{.11}{.891} \times 20\% = \underline{\underline{2.5\%}}$$

$$\text{90 Hz filter output} = \frac{.10}{.999} \times 20\% = \underline{\underline{2.0\%}}$$

It is of interest to note that the theoretical results taken from output of the computer program given in Table 28 were obtained with an IM carrier to desired signal ratio of -7.7dB. The measured IM to signal ratio was -10dB using AGC method and -8.3 dB by measuring detector voltage output with IM carrier and desired signal only and comparing it to a detector voltage with known modulation.

2. <u>"Flutter" of IM Relative to Desired Signal</u>. Several problems were observed during the experiments due to the narrow bandwidths of the 90 and 150 Hz filters. One was the "flutter" which is investigated using an intermod carrier and a desired signal as inputs to the receiver. The detector voltage was monitored with an oscilloscope and its frequency measured with a frequency counter. The resultant frequency was measured

to be approximately 100 Hz. The waveform observed was a sine wave with varying frequency due to slight frequency fluctuations in the desired frequency and IM frequency. The average frequency drift was estimated to be approximately 100 Hz. Since the 90 and 150 Hz filter functions have very sharp bandpass characteristics on the order of 30 Hz, the 100 Hz IM "flutter" becomes very significant.

For calculation purposes an approximation of the filter characteristics was used in the program to compute modulations factors for the 90 and 150 Hz filter characteristics. These factors vary as much as 25% with the modulation frequencies varying as little as a few hertz. The theoretical modulation factors did not agree well with the measured modulation factors which were found to vary little as the modulation frequencies were changed. In order to obtain useful theoretical modulation factors for the 90 and 150 Hz filters, ideal bandpass filters with the same noise equivalent bandwidth as the actual filter functions were used. The ideal bandpass filters have enough bandwidth so as to get a good sampling of the intermod generated. This is evidenced as observed in the good agreement between theoretical results and measured results. This method as given in Table 28 in the text seems to work. With low modulation indices and higher modulation frequencies (when the intermod does not have enough components which land in the receiver passband so as to make the intermod "look" noise-like) results will not agree as well.

Although the 90 Hz filter has a half power bandwidth of approximately 35 Hz, its noise equivalent bandwidth (found by integrating the measured filter characteristic numerically) is 168 Hz. This is because the skirts of its characteristics do not fall off rapidly.

Similarly the -3 dB bandwidth of the 150 Hz filter is 55 Hz and its noise equivalent bandwidth is 195 Hz.

3. Measurement of Modulation Factors. Modulation factors due to intermod are measured by inputting the IM carrier and desired signal into the receiver and measuring the filter output voltage. For the detector filter, the IM carrier frequency is set to the desired signal frequency. For the audio filter, the IM frequency is set to 1 KHz above or below the receiver frequency.

The interfering signals are then FM modulated (with the IM carrier frequency equal the receiver frequency) and the RMS output of the filter is measured.

The result of measuring the IM carrier filter voltage output is to provide a normalizing voltage. Variations in gain of various parts of the receiver are effectively divided out by using modulation factor measurements. This is especially true for the audio filter which has a gain determined by the setting of the volume control. (For measurement purposes, the volume control was replaced by a 10 turn trim pot and adjusted for 1/5 full volume.)

Measured values of modulation factors were found to agree very well with theoretical values. Measurements of the actual IM carrier level found by comparing the filter output voltage to an equivalent filter voltage with the desired signal AM modulated with a known percentage do not seem to agree as well. A disadvantage of the MF method is that the 90 and 150 Hz filter modulation factors cannot be measured this way since the IM carrier frequency cannot be adjusted to 90 or 150 Hz away from the desired frequency. Also it was found that the audio output overloads with more than 20% modulation.

E. Noise Equivalent Bandwidth. The noise equivalent bandwidth is defined as the bandwidth of an ideal filter with the same RMS output voltage as the actual filter. These concepts are illustrated in Figure E-1, where B_n is defined as the noise equivalent bandwidth, $\eta_i/2$ is the input spectral density of a "white" noise source and $S_o(f)$ is the output spectral density.

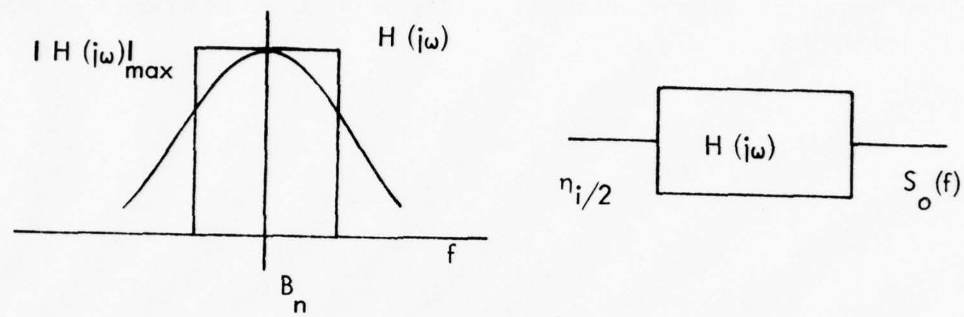


Figure E-1. Noise Equivalent Bandwidth of a Filter.

The RMS output voltage is given by

$$(N_o)\ RMS = \sqrt{\frac{\eta_i}{2} \int_{-\infty}^{\infty} |H(j\omega)|^2\, df} \qquad \text{(E-1)}$$

The noise equivalent bandwidth is then defined by

$$(N_o)\ RMS = \sqrt{\frac{\eta_i}{2} \int_{-\infty}^{\infty} |H(j\omega)|^2\, df} = |H(j\omega)|_{max} \sqrt{B_n \eta_i} \qquad \text{(E-2)}$$

and

$$B_n = \frac{\int_{o}^{\infty} |H(j\omega)|^2\, df}{|H(j\omega)|^2_{max}} \qquad \text{(E-3)}$$

It can be shown that the (MF) Ratio, i.e.,

$$\text{(MF) Ratio} = \frac{\text{Modulating Factor (MF) of Audio}}{\text{Modulating Factor (MF) of Detector}} = \frac{\sqrt{B_n \text{ Audio}}}{\sqrt{B_n \text{ Detector}}}$$

depends only on the filter functions or the noise equivalent bandwidths of the filters. Several calculations were made to verify these facts and the results are given in Table E-1. Note a very high modulation index and relative low modulation frequency are used to obtain a noise-like spectrum.

Station 1			Station 2					
Carrier Freq. in MHz	Modulation Freq. in KHz	Modulation Index	Carrier Freq. in MHz	Modulation Freq. in KHz	Modulation Index	Detector MF	Audio MF	MF Ratio
105.5	1.000	30.	102.5	.742	30.	.240	.113	.471
105.5	1.250	24.	102.5	1.042	24.	.241	.107	.444
105.5	.906	55.2	102.5	.543	55.2	.184	.085	.462

Table E-1. Comparison of Theoretical Modulation Factor Ratios From Computer Program.

Determination of the actual noise equivalent bandwidth B_n of the receiver filter (audio, detector, 90 and 150 Hz filters) requires numerical integration to find the area under the actual filter response curves. These characteristics were obtained for the NAV 11 receiver. The results obtained are:

Audio Filter (see Figure 18 of the text for response curve):

$$B_n = 1.08 \text{ KHz}$$

Detector filter (see Figure 17 of the text for response curve):

$$B_n = 4.93 \text{ KHz}$$

Using the above data the MF ratio is found to be

$$\text{(MF) ratio} = \frac{\sqrt{1.08 \text{ KHz}}}{\sqrt{4.93 \text{ KHz}}} = .468 \qquad \text{(E-4)}$$

Comparing this result with those given in Table E-1 it is seen that the MF ratio determined by filter characteristics and those from IM calculations using the computer program agree very well. Similar techniques can be applied to the 90 and 150 Hz filter functions. Because of the good agreement of the "noise" model of the IM, the 90 and 150 Hz filter functions were modeled in the computer program by a filter with the same noise equivalent bandwidth. See discussion in Appendix D.

F. CDI Interference. Figure 18 in the text shows the test setup used to determine the effects of high level modulation on the CDI response. These results are obtained by injecting a 108.501 MHz signal along with a desired signal of 108.500 MHz. The 108.501 MHz signal results in an injected 1 KHz sideband signal in the IF which is detected. Tables F-1, F-2, and F-3 give the results obtained.

The results given in Table F-4 show the CDI variations as a function of sideband frequency.

Interfering signal level relative to desired level	Measured CDI	Percent change in CDI reading due to sideband
-15 dB	58 μA	3%
-12 dB	55 μA	8%
-10 dB	51 μA	15%
- 8 dB	48 μA	20%
- 6 dB	42 μA	30%
- 3 dB	31 μA	48%

Table F-1. Effects of Detector Clipping on CDI (Normal Reading of CDI = 60 μA).

Interfering signal level relative to desired level	Measured CDI (μA)	Percent change in CDI reading due to sideband
-15 dB	30.7	3.4%
-12 dB	28.9	9.1%
-10 dB	27.7	12.9%
- 8 dB	25.8	18.8%
- 6 dB	21.0	34 %
- 3 dB	18.4	42 %

Table F-2. Effects of Detector Clipping on CDI (Normal Reading of CDI = 30 μA).

Interfering signal level relative to desired level	Measured CDI
-10 dB	1.6 μA
- 8 dB	2.0 μA
- 5 dB	3.3 μA
- 3 dB	6.0 μA

Table F-3. Effects of Detector Clipping on CDI (Normal Reading of CDI = 0 μA).

Fixing AGC at its value with no interfering signal present and introducing 1 KHz sideband, gives the same CDI deflections as before; therefore, the CDI interference is not due to AGC changes of the receiver.

Table F-4 shows the CDI reading as a function of sideband frequency. Interfering signal level is fixed at -3 dB lower than desired signal level (70% modulation).

Sideband frequency in KHz above desired level	Measured CDI
1 KHz	31.2 μA
2 KHz	29.0 μA
4 KHz	34.4 μA
6 KHz	38 μA
8 KHz	37.7 μA
10 KHz	32.5 μA
12 KHz	26.9 μA
15 KHz	49.7 μA

Table F-4. Effects of Interfering Signal Frequency on CDI (Normal Reading of CDI = 60 μA).

Note that the CDI values as the measured IF frequency response varies (see IF/detector characteristics, Figure 3). The CDI reading is lower at 12 KHz because of the peak in the side of the IF response. Likewise at 15 KHz, CDI is closer to its actual value.

G. User Manual

1. FM Interference Program Users Instructions. The FM interference program uses the measured characteristics of the Nav 11 receiver to predict the amount of interference due to high power FM stations. The program assumes sinusoidal modulation on the FM signals and that the interference is due to 3rd order nonlinearities in the RF amp of the receiver.

The user must supply the following information to analyze an interference situation: Number of FM stations, receiver frequency, distortion parameter 3/2 K3/K1. For each FM station, the following information is required: Station frequency, modulation frequency and modulation index, distance from the receiver and station power level. Localizer distance from the receiver and power level is also needed.

Most parameters for the program are entered in the edit mode. In this mode the user can enter parameters or modify them by typing commands at a remote terminal. The user may also exit the edit mode with the 'IM' command and begin intermodulation calculations, or begin signal level computations with the 'MXDB' command or start cross modulation calculations with the 'XMOD' command. "STOP' will cause the exiting of the edit mode and normal program execution. These commands allow flexibility in altering parameters and seeing their effects on the interference situation.

A summary of the program limitations are given below.

Program Limitations:

(1) A modulation index of 75 is a practical limit on the maximum modulation index that the program will accept. Modulation indices higher will cause extremely long program execution times. A modulation index of 75 corresponds to a maximum frequency deviation of 75 KHz with a modulation frequency of 1 KHz.

(2) The program assumes that the modulation frequencies of the FM stations are not harmonically related. For example frequencies of 1000 Hz and 400 Hz are related whereas 1000 Hz and 398 Hz are not. The intermodulation due to stations with harmonically related modulation frequencies has components which occur only at certain frequencies relative to the IM carrier and does not exhibit the "noise-like" (realistic) properties which are assumed for IM calculations. Harmonically related modulation frequencies will be treated as though they were not related by the program. Therefore, when using harmonically related frequencies such as 1000 Hz and 400 Hz, it is advisable to check the results to see if the same results are obtained as with frequencies of 1000 Hz and 398 Hz.

Before using the program, it is suggested that the user read the program subroutine descriptions given in this report. Also, the flow chart given in Figure G-1 is very useful in understanding the program. A sample terminal session is given on the following pages.

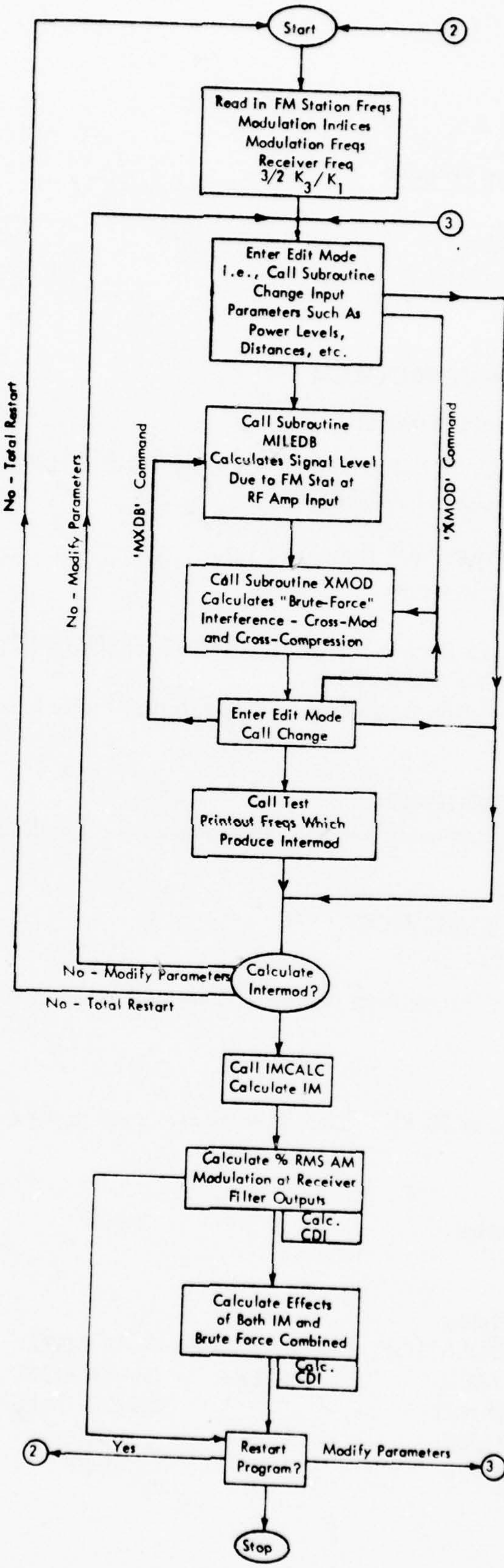


Figure G-1. Flow-Chart of FM Interference Program.

Sample Session of Interference Program

```
  load interfer ( start nomap
EXECUTION BEGINS . . .

START OF PROGRAM

        *** FM INTERFERENCE PROGRAM ***
```

Program is executed at a remote terminal

```
THIS PROGRAM CALCULATES THE INTERFERENCE DUE TO HIGH POWER FM STATIONS
  AND ITS EFFECTS ON A NAV 11 RECEIVER.

READ IN NUMBER OF FM STATIONS (FORMAT NN)
```

User enters no. of interfering stations

```
.02
TYPE STATION FREQUENCIES IN MHZ, MODULATING FREQUENCY IN KHZ,MODULATION
INDEX(FORMAT XXXXXYYYYYZZZZZ)
```

The station frequency, modulation frequency and modulation index is inputted for each station

```
.105.512.50 5.0
.102.510.42 5.
TYPE RECEIVER CENTER FREQUENCY
```

.108.5 User enters receiver frequency which is the same as the localizer frequency

```
TYPE 3/2 K3/K1 IN DB
```

.3. The distortion parameter

```
*** PROGRAM PARAMETER EDIT MODE ***
  FOR INSTRUCTIONS TYPE: INST
```

Edit mode is entered. The distance from station 1 is set at 5 miles. From station 2 is 4 miles.

```
. MILE 01  5.
. MILE 02  4.
```

Power level for both stations is 50 Kw. Localizer power is set to 40 w.

```
.POWER 00  50.
.POWER 20  .040
```

Distance to localizer is 2 miles.

```
.MILE 20  2.
.TYPE 00
```

FM station parameters are listed

STATION NUMBER	STATION FREQ (MHZ)	MODULATION FREQ (KHZ)	MODULATION INDEX	MAX FREQ DEVIATION (XMOD CALC)	LEVEL AT RF AMP INPUT=DBM	MILES FROM RECEIVER
1	105.5	12.500	5.00	0.0	0.0	5.0
2	102.5	10.420	5.00	0.0	0.0	4.0

.TYPE 20

Localizer parameters are listed

STATION NUMBER	STATION FREQ (MHZ)	MODULATION FREQ (KHZ)	MODULATION INDEX	MAX FREQ DEVIATION (XMOD CALC)	LEVEL AT RF AMP INPUT=DMB	MILES FROM RECEIVER
20	108.5	0.0	0.0	0.0	0.0	2.0

.STOP

End of edit mode command

TO COMPUTE SIGNAL LEVEL AT RF AMP INPUT TYPE 1
OTHERWISE VALUES OF LEVEL (I) MUST BE INITIALIZED IN THE
EDIT MODE AND USED AS THE SIGNAL LEVEL AT THE RF AMP INPUT

.1

Signal levels at RF amp are calculated.

PRINTOUT OF SIGNAL LEVEL COMPUTATIONS

STATION FREQ (MHZ)	MILES FROM RECEIVER	STATION POWER IN DBM	FREE SPACE ATTEN-DB	NAV ANTENNA LOSS-DB	RCVR INPUT FILTER ATTEN DB	SIGNAL LEV AT RFAMP IN (DBM)
105.5	5.0	77.0	90.7	3.0	4.5	-15.3
102.5	4.0	77.0	88.6	6.0	9.0	-20.6
LOCALIZER SIGNAL LEVEL CALCULATIONS:						
108.5	2.0	46.0	83.0	0.0	0.0	-31.0

TO USE MAXIMUM FREQUENCY DEVIATION SPECIFIED BY MODULATION FREQUENCY AND MODULATION INDEX TYPE 1, OTHERWISE FQDEV (I) MUST BE SPECIFIED

.1

Cross mod and cross compression calculations made

********* CROSS MODULATION CALCULATIONS *********

STATION FREQ (MHZ)	COMPRESSION OF LOC. SIGNAL IN DB	FREQ DEV. FOR XMOD CALC.(KHZ)	% AMMOD CAUSED BY STAT.
105.5	0.8	63.	0.12
102.5	0.2	52.	0.02

TOTAL PERCENT MOD., NOT CONSIDERING CROSSCOMPRESSION = 0.01
COMPRESSION FACTOR = 0.109
LOCALIZER SIGNAL COMPRESSION IN DB = 1.0
TOTAL % RMS UNFILTERED AM MODULATION = 0.12

****

Filtered AM modulation due to crossmod is printed.

TOTAL RMS AM MODULATION
DUE TO CROSSMOD INTERFERENCE
CROSSCOMPRESSION EFFECTS INCLUDED

DETECTOR OUTPUT AM MODULATION: 0.1 %
AUDIO OUTPUT AM MODULATION: 0.0 %
150 HZ FILTER OUTPUT AM MODULATION: 0.0 %
90 HZ FILTER OUTPUT AM MODULATION: 0.0 %

Re-entry of edit mode by program
*** PROGRAM PARAMETER EDIT MODE * * *
FOR INSTRUCTIONS TYPE: INST

./ End of edit mode - no parameters altered.

Printout of intermod generating frequencies:
RECEIVER FREQUENCY IS 108.50 RECEIVER BANDWIDTH IS 40.0 KHZ
FREQUENCIES WHICH PRODUCE INTERMOD INTERFERENCE ARE:

F1	F2	F3	IM TYPE	IM CENTER FREQ	IM BW IN KHZ	IM LEVEL IN DBM
105.5	102.5		2F1-F2	108.50	425.	-48.5

TO CALCULATE INTERMOD SPECTRUM TYPE 0, TYPE 1 TO STOP, TYPE 2 TO RESTART PROGRAM, TYPE 3 TOCHANGE PARAMETERS AND RECALCULATE INTERFERENCE
.0
IM is calculated

****

INTERMOD AM MODULATION CALCULATIONS:

....

CALCULATION PARAMETERS :

INTERMOD TYPE: 2F1-F2

	STATION FREQ (MHZ)	MODULATION FREQ (KHZ)	MODULATION INDEX
F1:	105.5	12.500	5.0
F2:	102.5	10.420	5.0

INTERMOD LEVEL (NO FM STATION MODULATION) = -48.1 DBM

DETECTOR MODULATION FACTOR = 0.156
AUDIO OUTPUT MODULATION FACTOR = 0.032
150 HZ FILTER MODULATION FACTOR = 0.0
RMS AM MODULATION AT DETECTOR OUTPUT = 2.2%
RMS AM MODULATION AT AUDIO OUTPUT = 0.4%
RMS AM MODULATION AT 150 HZ FILTER OUTPUT = 0.0%
RMS AM MODULATION AT 90 HZ FILTER OUTPUT = 0.0 %

```
FOR PRINTOUT OF TOTAL INTERFERENCE TYPE 1
.0
Typing a '1' will print out total interference due to intermod, CDI interference and
combined crossmod and intermod.
********************************************************************************
TO STOP TYPE 0, TO MODIFY PARAMETERS TYPE 1, FOR TOTAL RESTART TYPE 2
.0
                End of program execution
R;
```

H. Subroutine Descriptions. In this Appendix we briefly describe each subroutine used and its purpose. Figure H-1 shows a block diagram of the various subroutines and functions used in the interference program. Each of these will be explained in detail in this report. Figure G-2 in Appendix G gives a flow-chart of the main program. Table H-1 gives a listing of the variable names used and each of their meanings.

1. Subroutine CHANGE. This subroutine is entered in the parameter edit mode. The program parameters are changed by typing the proper instruction. The instructions can also cause the program to exit edit mode and continue normal execution or jump and perform certain tasks such as calculate IM immediately, calculate signal levels at RF amp input, etc. A list of instructions and what action they take is given in Table H-2.

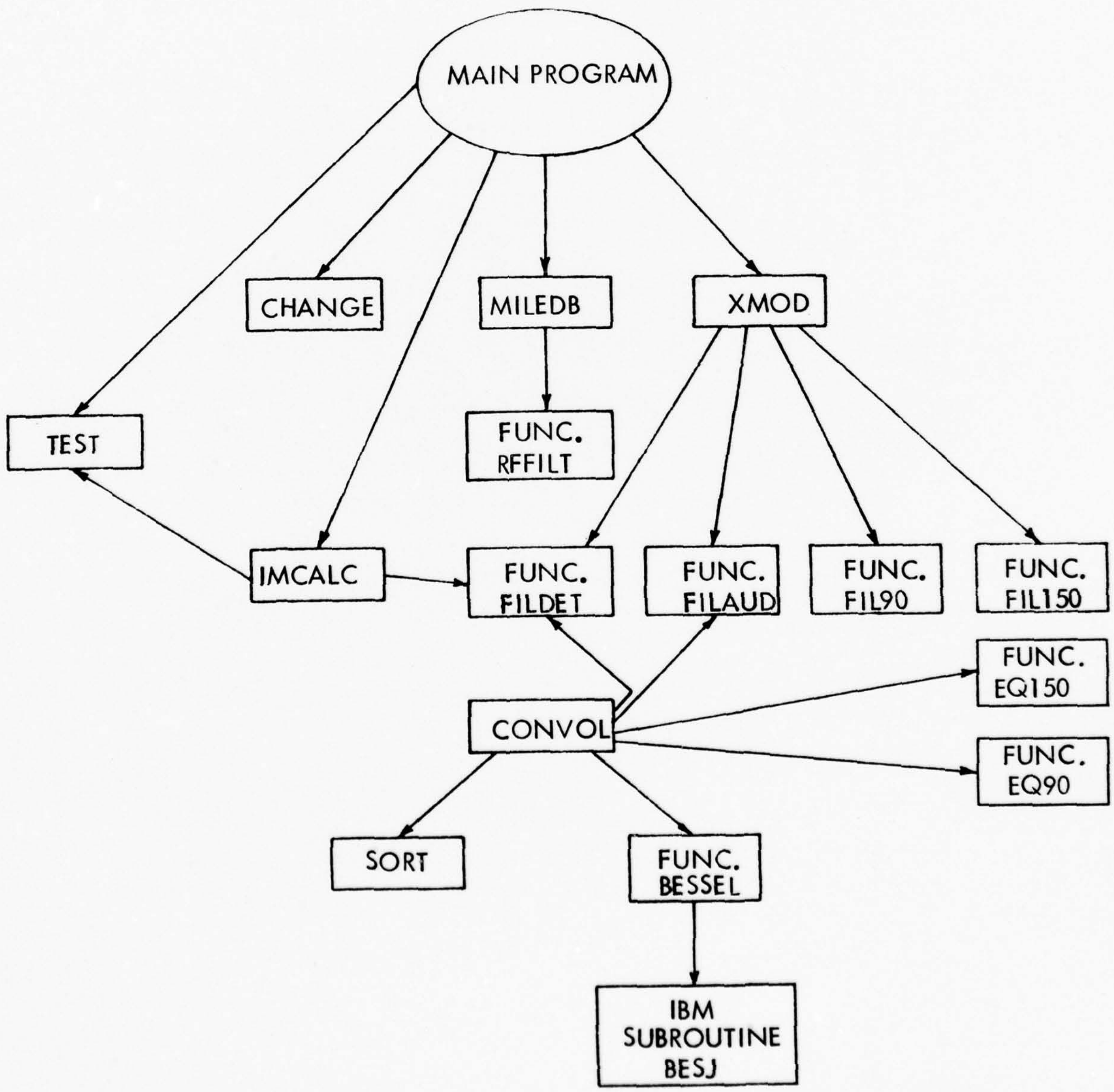


Figure H-1. Subroutine ana Functions Called by the Main Program.

VARIABLES:

NSTAT IS THE NUMBER OF FM INTERFERING STATIONS

FREQ (I) IS THE FREQUENCY IN MHZ OF THE ITH FM STATION

FMOD (I) IS THE MODULATING FREQUENCY FOR STATION I

BETA (I) IS IT'S MODULATION INDEX

LEVEL (I) IS THE SIGNAL LEVEL OF THE I TH FM SIGNAL.
IT IS THE SIGNAL LEVEL AT THE RF AMP INPUT I.E.
IT IS THE LEVEL AT THE RECEIVER INPUT TERMINAL MINUS
THE ATTENUATION OF THE INPUT FILTER

MILE (I) IS THE DISTANCE FROM THE RECEIVER TO THE ITH STATION IN MILES

POWER (I) IS POWER LEVEL OF THE ITH STATION IN KWATTS

FQRCVR IS THE CENTER FREQUENCY THAT THE RECEIVER IS TUNED TO, GIVEN IN MHZ

BW IS THE BANDWITH OF THE RECEIVER IN KHZ. I.E. THE RECEIVER BANDWIDTH.
IT IS ASSUMED TO BE IDEAL BANDPASS
IT IS GIVEN THE VALUE OF 40 KHZ

RK3K1 IS THE DISTORTION PARAMETER 3 K3/2 K1 IN DB.

Table H-1. Variable Names and Their Meaning.

IN PARAMETER EDIT MODE ALL COMMANDS ARE TYPED AS:

XXXXXNNYYYYYYYYYYY

WHERE XXXXX IS THE COMMAND
NN IS THE STATION NUMBER
YYYYYYYYYYY IS THE PARAMETER FIELD (FORMAT F13.6)

IF NN IS OO THEN ALL STATIONS ARE AFFECTED EXCEPT FOR STATION NO 20
WHICH IS THE STATION CODE NUMBER GIVEN TO THE LOCALIZER
EACH FM STATION HAS A STATION NO. (INPUT TYPE OO FOR THE STATION NUMBERS)

POSSIBLE COMMANDS:

INST-PRINTS OUT THESE INSTRUCTIONS
TYPE NN - PRINTS OUT PARAMETERS FOR STATION NN
STOP - ENDS EDIT MODE
/ - ENDS EDIT MODE
CONT - ALSO ENDS EDIT MODE
FREQ NNYYYY - CHANGES STATION NN FREQUENCY TO YYYY MHZ
FMOD NNYYYY - CHANGES MODULATION FREQUENCY OF STAT. NN TO YYYY
BETA NNYYYY - CHANGES THE MODULATION INDEX OF STATION NN TO YYYY
MILE NNYYYY - CHANGES THE DISTANCE FROM THE RECEIVER OF STAT. NN TO YYYY MILES
LEVEL NNYYYY - CHANGES THE SIGNAL LEVEL DUE TO STAT. NN AT RECEIVER INPUT TO YYYY DBM
POWER NNYYYY - CHANGES STATION NN POWER LEVEL TO YYYY KWATTS
FQDEV NNYYYY - CHANGES FREQUENCY DEVIATION OF STAT. NN TO YYYY KHZ (ONLY USED IN CROSSMOD CALC.)
MXDB - TRANSFERS PROGRAM CONTROL FROM EDIT MODE TO CALCULATE SIGNAL LEVELS FROM DISTANCE TO RECEIVER
IM - INTERMOD INTERFERENCE IS CALCULATED
XMOD - CALCULATIONS OF CROSSMOD INTERFERENCE ARE MADE

Table H-2. Edit Mode Commands.

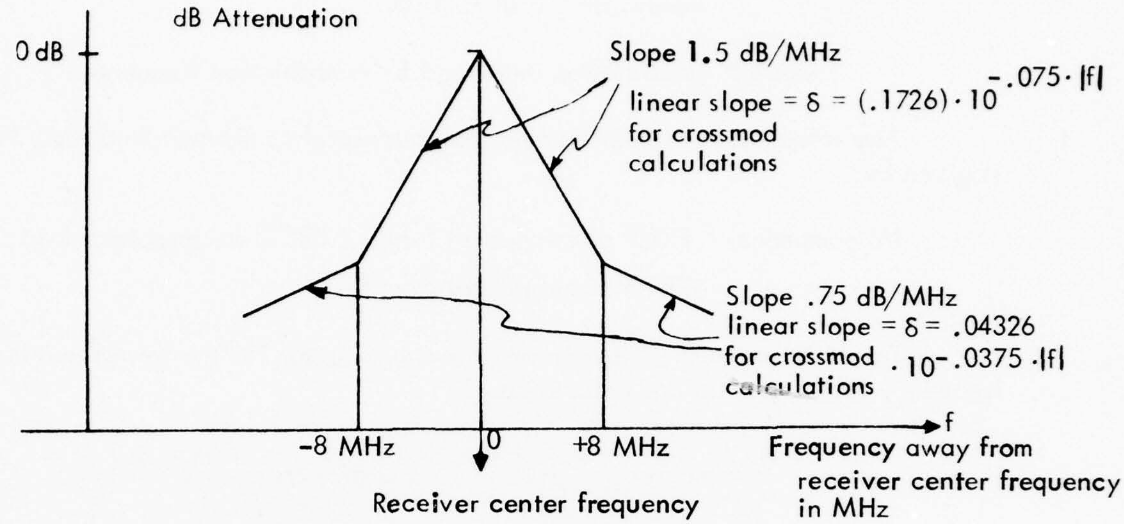


Figure H-2. Assumed Attenuation Characteristics.

2. Subroutine MILEDB. MILEDB calculates the signal level at the RF amp input of the receiver using the free space attenuation formula. It takes into account NAV antenna loss (1 dB/MHz below 108.5 MHz) and the RF amp input filter characteristics. The free space attenuation formula is

α (attenuation in dB) = 36.3 + 20 log (freq. in MHz) + 20 log (d in miles)

The signal level in dBm at the RF amp input due to station I:

Level (I) = Power (I) in dBm - Free Space Atten. (I) - NAV Antenna Loss

- Loss Due to RF Amp Input Filter + 6dB

(The 6dB is due to the directive gain of the NAV 11)

The loss due to the RF amp input filter characteristics is calculated by REAL FUNCTION RF FILTER. The attenuation characteristics of the NAV 11 receiver are approximated by the characteristics given in Figure H-2.

3. Subroutine TEST. This subroutine checks to see if there is 3rd order IM due to stations I, J, K which lands within the receiver passband. The program uses the relation given below to calculate the bandwidth of FM signal spectra of stations I, J, K.

$$\text{Bandwidth} = 2\,(\beta + 1)\ fm$$

where β = modulation index and fm = modulation frequency.

Any intermod component formed from a spectral component from each FM station is given by:

IM component = FREQ of component from I + FREQ of component from J - FREQ of component from K

To see if any of these IMs are within the receiver BW the lowest and highest frequency IM component are calculated.

$$IM_{max} = F1_{carrier\ freq} + fm_1\,(1 + \beta_1) + F2_{carrier\ freq} + fm_2\,(1 + \beta_2) - F3 + fm_3\,(1 + \beta_3) \qquad (H-1)$$

Likewise,

$$IM_{min} = F1_{carrier\ freq} - fm_1\,(1 + \beta_1) + F2_{carrier\ freq} - fm_2\,(1 + \beta_2) - F3 - fm_3\,(1 + \beta_3) \qquad (H-2)$$

The receiver frequency is denoted by FQRCVR in the program and if there is IM interference, then

$$IM_{freq\ min} \leq FQRCVR \pm 20\ KHz \leq IM_{Freq\ Max}$$

For these calculations, the bandwidth of the receiver is assumed to be 40 KHz.

4. Subroutine XMOD. XMOD calculates the amount of cross-compression and cross-modulation due to interfering FM stations. The program uses either the maximum frequency deviation calculated from BETA (I) and the modulation frequency FMOD (I) or FQDEV (I) (the maximum frequency deviation is entered in edit mode). The user can specify which to use. Entering the maximum frequency deviation for crossmod calculations allows the user to analyze interference situations easier without specifying a BETA or FMOD for each FM station. FQDEV = 40 KHz might be a "typical" value for example.

The gain change (GC) of the desired signal due to station I is calculated.

$$GC = \frac{\text{Desired signal amplitude with interference}}{\text{Desired signal amplitude without interference}} = 1 - 3K_3/K_1\ B_i^2 \qquad (H-3)$$

where B is the signal level of the Ith FM station at the RF amp input. At this point it is assumed that the RF amp input filter attenuation has already been taken into account.

The gain change in dB is:

$$GC_{dB} = 20 \log \{ 1 - (10^{((3K_3/2K_1)dB + 2B\,dBm + 6)/20} \} \qquad (H\text{-}4)$$

Total GC due to all stations is given by

$$GC_{total} = 1 - \frac{3K_3}{K_1} \sum_{i=1}^{N} Bi^2 \qquad (H\text{-}5)$$

where Bi is the signal level due to the Ith station at the RF amp input.

The amount of cross-modulation due to station I is:

$$\% \text{ Am mod} = \text{Max Freq Dev of FM Station} \cdot \text{Slope of Input RF Amp Filter}$$

$$\cdot 6K_3/K_1 \cdot B_i^2 \times 100\% \qquad (H\text{-}6)$$

(not considering cross-compression)

Equation (H.6) does not consider cross-compression of the carrier. If one wants to consider cross-compression, the equation used is

$$\begin{matrix}\% \text{ Am Mod with} \\ \text{compression}\end{matrix} = \frac{\begin{matrix}\% \text{ Ammod without} \\ \text{Cross-Compression}\end{matrix}}{1 - \frac{3K_3}{K_1} B^2} \qquad (H\text{-}7)$$

The total RMS Am cross-modulation due to N stations is given by:

$$\text{Total RMS \% Am} = \frac{\left[\sum_{i=1}^{N} (f\,max_i \cdot \delta_i \cdot \frac{6K_3}{K_1} B_i^{2})^2 \right]^{\frac{1}{2}}}{1 - \frac{3K_3}{K_1} \Sigma B_i^2} \qquad (H\text{-}8)$$

where $f\,max_i$ = maximum frequency deviation of station I

δ_i = slope of input filter characteristics at frequency of station I

Subroutine XMOD calculates % Am mod at the receiver filter outputs also. It uses the same equation as above except that each term is weighted by y ($f\,mod_i$), where y is the appropriate normalized filter function and $f\,mod_i$ is the modulation frequency of the Ith interfering FM station. Note that if FQDEV (I) is only specified, the filtered % cross-mod calculations will not be accurate since $f\,mod_i$ must be specified. The % modulation present at the receiver filter output due to interfering signals is:

$$\text{Total RMS \% Am Modulation at a Receiver Filter Output} = \frac{\left\{ \sum_{i=1}^{N} \left(f\,max_i \cdot \delta_i \cdot \frac{6K_3}{K_1} B_i^2 \cdot y\,(f\,mod_i) \right)^2 \right\}}{1 - \frac{3K_3}{K_1} \sum B_i^2} \qquad \text{(H-9)}$$

Table H-3 gives a listing of the variable names used in Subroutine XMOD.

```
VARIABLE NAMES:

CROSSL-LINEAR COMPRESSION FACTOR FOR ONE STATION ONLY (ITH STATION)
         I.E.3  K3/K1  B**2 WHERE B IS THE SIGNAL LEVEL OF THE ITH
         STATION AT THE RF AMP INPUT.
PERCNT - % CROSSMOD OF LOCALIZER SIGNAL DUE TO STATION I, CROSS
         COMPRESSION NOT CONSIDERED
PERCOM - % AM MOD DUE TO STATION I CONSIDERING CROSSCOMPRESSION
SUMC - COMPRESSON FACTOR DUE TO ALL STATIONS. (RESULTANT LOC. LEVEL
         IS MULTIPLIED BY (1-SUMC)
SUMCDB - COMPRESSION OF LOC. SIGNAL DUE TO ALL FM STAT. EXPRESSED IN
         DB.I.E. SUMCDB=20 LOG (1-SUMC)
XMOD1 - TOTAL % RMS AM MOD AT THE DETECTOR OUTPUT DUE TO
         CROSSMOD FROM ALL STAT. (IT INCLUDES EFFECTS OF
         CROSSCOMPRESSION ONLY IF SUMC IS LESS THAN 1)
XMOD2 - % RMS AM MOD AT THE RECEIVER AUDIO OUTPUT
XMOD3 - % RMS AM MOD AT 150 HZ FILTER OUTPUT OF RECEIVER
XMOD4 - % RMS AM MOD AT 90 HZ FILTER OUT
```

Table H-3. Variable Names For Subroutine XMOD.

5. Subroutine IMCALC. This subroutine calculates the AM modulation due to intermod interference.

IMCALC checks all combinations of 3 stations (stations I, J, K) to see if the 3rd order intermod causes interference at the receiver frequency. This is done by calling Subroutine TEST which checks the 3 freqs and returns with ITEST = 1 if they produce interfering IM. Subroutine CONVOL is called which does the convolution of the 3 FM spectra and returns with the modulation factors of the receiver filter outputs (called SUMDET, SUMAUD, SUM150, SUM90). IMCALC uses the modulation factors to calculate the % RMs AM modulation at the filter outputs.(called PER 1, PER 2, PER 3, PER 4) Total % AM modulation due to the IM from all interfering stations is summed (called TOTAL I, TOTAL 2, etc.). The CDI with interference is calculated by calling subroutine

CDI. The above calculations do not consider effects of brute force interference. The combined effects of cross-mod, cross compression, and intermod are added and printed out. CDI calculations are again made.

A listing of the variable names used in the IM % AM modulation are:

TOTAL 1 is the total % RMS AM mod due to all FM stations at the output of the detector filter
TOTAL 2 is % at the audio output
TOTAL 3 is the % at the 150 Hz output
TOTAL 4 is the % at the 90 Hz filter output.

PER 1 is the % AM mod due to IM from stations I, J, K only at the detector filter output.
PER 2 is the % AM mod due to stat. I, J, K at the audio output.
PER 3 is the % AM mod at the 150 Hz filter output.
PER 4 is the % AM mod at the 90 Hz output.

The IM level due to 2F1-F2 IM is given by

$$IM_{\text{carrier level}} = 3/2 \frac{K_3}{K_1} B^2 C \qquad \text{(H-10)}$$

where B and C are signal levels at the RF amp input of FM station 1 and FM station 2. The IM level due to F1 + F2 - F3 IM type is:

$$IM = 3 \frac{K_3}{K_1} BCD \qquad \text{(H-11)}$$

where B, C, D are signal levels of stations 1, 2, and 3 respectively.

The % Am modulation due to intermod carrier only is (no FM modulation on the FM stations):

$$\begin{matrix}\text{\% Am mod due} \\ \text{to IM carrier}\end{matrix} = 10^{-\left(\begin{matrix}\text{Localizer} \\ \text{level in} \\ \text{dBm}\end{matrix} - \begin{matrix}\text{IM carrier} \\ \text{level in} \\ \text{dBM}\end{matrix}\right)/20} \cdot 100\% \qquad \text{(H-12)}$$

The RMS AM Modulation due to the IM with modulation is

$$\text{\% RMS Am modulation} = \begin{matrix}\text{\% Am modulation due} \\ \text{to carrier alone}\end{matrix} \cdot \text{Modulation factor} \qquad \text{(H-13)}$$

Total RMS % modulation due to all IM is given by

$$\text{Total RMS \% mod} = \left(\sum_{\substack{\text{all} \\ \text{intermods}}} \begin{matrix}\% \ Am^2 \text{ mod due to} \\ \text{IM from 3 stations}\end{matrix} \right)^{1/2} \quad (H-14)$$

Including effects of cross-compression and cross modulation as well as IM results in a total RMS percent modulation given by,

$$\begin{matrix}\text{Total RMS \% mod due} \\ \text{to IM and brute force} \\ \text{with cross-compression}\end{matrix} = \frac{\begin{matrix}(\text{total RMS \% Am mod due to } IM^2 + \text{Total } Am^2 \text{ mod} \\ \text{due to brute force, AM mod from cross-modulation} \\ \text{without cross-compression})\ 1/2\end{matrix}}{GC} \quad (H-15)$$

$$\text{where } GC = 1 - 3 \frac{K_3}{K_1} \Sigma B_i^2 \quad (H-16)$$

which is the gain change due to "brute force" interference due to all FM stations.

6. Subroutine CONVOL. Subroutine CONVOL calculates the 3rd order intermod due to interfering tone modulated FM stations. There are two types of intermod possible, 2F1 - F2 type and F1 + F2 - F3.

The 2F1 - F2 intermod is due to 2 FM stations with an IM center frequency = 2F1 - F2, where F1 is the carrier frequency of the one FM station, F2 is the carrier level of the other.

F1 + F2 - F3 intermod is due to 3 FM stations and has a carrier frequency of F1 + F2 - F3. The subroutine CONVOL handles each type separately.

a. 2F 1 - F2 IM Term. For 2F1 - F1 intermod, the IM is

$$\begin{matrix}\text{IM} \\ \text{terms}\end{matrix} = \frac{3}{2} B^2 C\ \alpha(b)^2\ \alpha(c) \sum_{k=-(\beta_1+1)}^{\beta_1+1} \ \sum_{m=-2\beta_2+1}^{2\beta_2+1} J_m (2\beta_2) J_k (\beta_1) \quad (H-17)$$

$$\cdot \cos 2\pi t\ (2b - c + m \cdot fm_2 - k \cdot fm_1)$$

Thus the (m, k) th intermod term is

$$IM_{m,k} = \underbrace{J_k (\beta_1)\ J\ (2\beta_2)}_{Am,\ n} \cos\ [\ 2b - c + mfm_2 - kfm_1\ ] \quad (H-18)$$

The modulation factor is calculated by

$$MF = \Big(\sum_{\substack{\text{all terms with} \\ \text{frequencies within} \\ \text{receiver passband}}} Am, k \cdot |y\ (f)| \Big)^{1/2} \qquad \text{(H-19)}$$

where f = IM carrier frequency - Receiver frequency + $m \cdot fm_2 - k \cdot fm_1$.

In this equation, y(f) is the normalized filter function of one of the receiver filter outputs and f is the frequency of the IM term relative to the receiver center frequency. y (f) is assumed symmetrical with respect to frequency. The maximum value of the modulation factor is 1 and this occurs only if all IM terms are received in the receiver passband and y(f) = 1.

b. <u>F1 + F2 - F3 IM Term</u>. The F1 + F2 - F3 intermod term is given by:

$$\underset{\text{terms}}{IM} = 3\ B\ C\ D\ \alpha(b)\ \alpha(c)\ \alpha(d) \sum_i \sum_j \sum_k J_i(\beta_1)\ J_j(\beta_2)\ J_k(\beta_3) \cos 2\pi t \qquad \text{(H-20)}$$

$$(F1 + F2 - F3 + ifm_1 + jfm_2 - kfm_3)$$

For convenience let

$$A\,i\,j\,k = J_i(\beta_1)\ J_j(\beta_2)\ J_k(\beta_3) \qquad \text{(H-21)}$$

Using (H-21) the modulation factor (MF) is given by

$$\text{Modulation factor} = \Big(\sum_{\substack{\text{all IM terms} \\ \text{that pass through} \\ \text{receiver bandwidth}}} A\,i\,j\,k|y\ (f)| \Big)^{1/2} \qquad \text{(H-22)}$$

where

$$f = F1 + F2 - F3 + ifm_1 + jfm_2 - kfm_3 \qquad \text{(H-23)}$$

$$- \text{Receiver center frequency}$$

The program stores in Array A X B and array A X BFQ the intermediate result of convolving two stations together. In addition, A X B holds the amplitude and A X BFQ contains the relative frequency of the intermediate result.

For a two-station case the intermod is

$$A\ X\ B\ (I) = J_{L-I-1}\ (2\ \beta_1) \qquad \text{(H-24)}$$

and

$$A\,X\,BFQ\,(I) = (L - I - 1) \cdot fm_1 \qquad (H\text{-}25)$$

where I ranges from 1 to 2L - 1
and L = integer value of $|(2\beta_2 + 1)|$

Similarily for a three-station case the IM is

$$A\,X\,B\,(I) = J_L(\beta_1)\,J_n(\beta_2) \qquad (H\text{-}26)$$

$$A\,X\,BFQ\,(I) = L \cdot fm_1 + m \cdot fm_2 \qquad (H\text{-}27)$$

where A X B and A X BFQ have been sorted in order of ascending frequency and L and M are indices which range from

$$INT\ [-(\beta_1 + 1)] \leq L \leq INT\ [\beta_1 + 1] \qquad (H\text{-}28)$$

$$INT\ [-(\beta_2 + 1)] \leq M \leq INT\ [\beta_2 + 1] \qquad (H\text{-}29)$$

(Note - INT stands for take integer value)

c. Convolution of AXB with the Spectrum of Station K. A flow chart of the program part of subroutine that convolves the intermediate result AXB with spectrum of F3 (or F2 in the case of 2F2 - F2 IM), is given in Figure H-3. To save computation time in calculating which intermodulation components fall into the receiver passband the program uses the fact that AXB is ordered as to increasing frequency. The intermodulation frequency is given by:

$$\underset{\text{frequency}}{\text{IM component}} = \underset{\text{frequency}}{\text{IM carrier}} + A\,X\,BFQ\,(I) - K^* fm_3 \qquad (H\text{-}30)$$

The program starts with K = 1 and begins to search through the array AXBFQ for an intermodulation component that lands just inside the low end of the receiver passband. When it is found, the value I is stored so that when K is incremented after going through the entire array AXBFQ, a search starts at that value of I, called LAST in the program, for the next value of IM which just falls within the receiver passband. Note that when the IM components begin to fall outside of the high end of the receiver passband, AXBFQ needs no longer to be searched since all other components will produce IM terms higher in frequency. So, K is then incremented and search begins through AXBFQ again.

This program calls subroutine SORT which is a bubble sort program to put the elements of A X B and AXBFQ in order. It is called only for F1 + F2 - F3 IM.

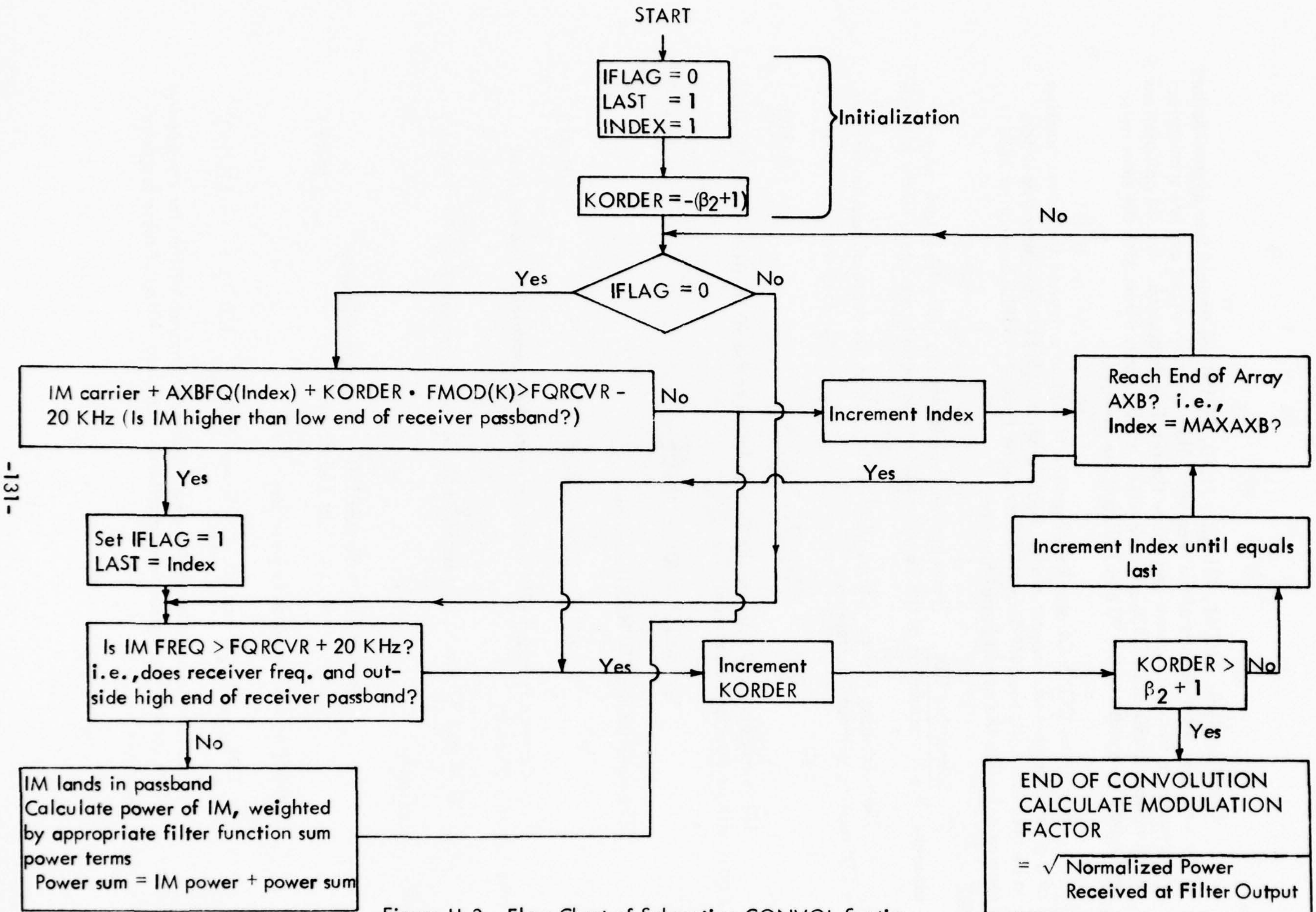


Figure H-3. Flow Chart of Subroutine CONVOL, Section Where AXB is Convolved with Station "K".

Real Functions: FILDET, FILAUD, FIL90, FIL150 are straight line approximations of the measured filter outputs of the receiver. They are normalized and are symmetrical with respect to frequency above and below the receiver frequency. For IM calculations real functions EQ90 and EQ150 are used which are bandpass filters with the same noise equivalent bandwidth as the 90 and 150 Hz filter functions.

Subroutine CONVOL uses Real Function BESSEL to calculate the bessel function of a given argument and integer order. Real Function BESSEL allows negative orders to be used and calls the IBM Scientific Subroutine Package (SSP). Subroutine BESJ is used to calculate the actual bessel function.

7. Subroutine CDI. This subroutine calculates the CDI with interference present. The % modulation at the 90 and 150 Hz filter outputs are inputs to the program.

The subroutine first calculates DDM (difference in the depth of modulation) for a CDI reading without interference.

$$DDM = CDI \cdot 15.5/150\,\% \qquad (H-31)$$

Let % modulation 90 denote the % modulation at the 90 Hz filter due to localizer signal with no interference present, i.e.,

$$\%\ mod\ 90 = 20\% + DDM/2 \qquad (H-32)$$

Likewise, for the 150 Hz filter output,

$$\%\ mod\ 150 = 20\% - DDM/2 \qquad (H-33)$$

If interference is added with a certain percentage modulation the resultant modulation is given by:

$$\%\ mod\ 90\ new = (\%\ mod\ 90^2 + \%\ mod\ interference\ 90^2)^{1/2} \qquad (H-34)$$

Similarily,

$$\%\ mod\ 150_{new} = (\%\ mod\ 150^2 + \%\ mod\ interference^2_{at\ 150\ Hz\ out})^{1/2} \qquad (H-35)$$

The resulting CDI response is given by:

$$CDI_{NEW} = (\%\ mod\ 90_{new} - \%\ mod\ 150_{new}) \cdot 150/15.5 \qquad (H-36)$$

In this section the basic operation of the computer program written for considering cases of multiple interfering signals was described. Complete listing of these programs is given in Appendix I.

I. Computer Program Listing

```
C*****************************************************************************
C*****************************************************************************
C*****************************************************************************
C*****************************************************************************
C
C
C
C
C       FM INTERFERENCE PROGRAM ..................
C
C       THIS PROGRAM CALCULATES THE INTERFERENCE DUE TO MULTIPLE
C       FM SIGNALS AND ITS EFFECTS ON A NAV 11 RECEIVER.
C
C       THE INTERFERENCE IS DUE TO  3RD ORDER NONLINEARITY IN THE
C       NAV RECEIVER
C       THE PROGRAM CALCULATES BRUTE FORCE AND CROSS MOD INTERFERENCE
C       DUE TO TONE MODULATED FM STATIONS
C
C
C           WRITTEN BY T. LOOS
C             AVIONICS ENGINEERING CENTER
C             OHIO UNIV., ATHENS OH.
C             JAN. 1978
C
C
C*****************************************************************************
C*****************************************************************************
C*****************************************************************************
C*****************************************************************************
C
C
C        PROGRAM VARIABLES:
C
C
C
C       NSTAT IS THE NUMBER OF  FM INTERFERING STATIONS
C
C       FREQ(I) IS THE FREQUENCY IN MHZ OF THE ITH FM STATION
C
C       FMOD (I) IS THE MODULATING FREQUENCY FOR STATION I
C
C       BETA(I) IS IT'S MODULATION INDEX
C
C       LEVEL(I) IS THE SIGNAL LEVEL IN DBM OF THE I TH FM STATION AT THE
C          RF AMP INPUT I.E. THE LEVEL AT THE RECEIVER INPUT MINUS
C          THE ATTENUATION DUE TO RF AMP INPUT FILTER.
C
C       MILE(I) IS THE DISTANCE FROM THE RECEIVER TO THE ITH STATION IN
C             MILES.
C
C       POWER(I) IS POWER LEVEL OF THE ITH STATION IN KWATTS
C
C       FQRCVR IS THE RECEIVER CENTER FREQUENCY IN MHZ.
C
C       BW IS THE BANDWITH OF THE RECEIVER IN KHZ. I.E.THE RECEIVER IF
```

```
C           BANDWIDTH. IT IS ASSUMED TO BE IDEAL BANDPASS
C           IT IS GIVEN THE VALUE OF 40 KHZ.
C
C        RK3K1 IS THE DISTORTION PARAMETER 3 K3/2 K1 IN DB.
C
C
C*************************************************************************
C*************************************************************************
C*************************************************************************
C*************************************************************************
C
        DIMENSION FREQ(20),FMOD(20),BETA(20)
C
      REAL MILE(20),POWER(20),FQDEV(20)
      REAL LEVEL(20)
C
        COMMON FQRCVR,XMOD1,XMOD2,XMOD3,XMOD4,SUMC,BW,RK3K1
        COMMON FREQ,LEVEL,FMOD,BETA
        COMMON MILE,POWER,FQDEV,NSTAT
C
C.... READ IN OF PROGRAM PARAMETERS ....
C
        PRINT 8
8       FORMAT(//,'     *** FM INTERFERENCE PROGRAM *** ',//,
      C ' THIS PROGRAM CALCULATES THE INTERFERENCE DUE TO HIGH POWER FM S
      CTATIONS',/,'  AND ITS EFFECTS ON A NAV 11 RECEIVER.',//)
1        PRINT 9
9       FORMAT(' READ IN NUMBER OF FM STATIONS (FORMAT NN)')
         READ 10,NSTAT
10      FORMAT(I2)
        PRINT 11
11      FORMAT('  TYPE STATION FREQUENCIES IN MHZ,MODULATING FREQUENCY ',
      C'IN KHZ,MODULATION INDEX',/,'  (FORMAT XXXXXYYYYYZZZZZ)')
        DO 12 I=1,NSTAT
        READ13,FREQ(I),FMOD(I),BETA(I)
12       CONTINUE
13       FORMAT(F5.1,2F5.0)
        PRINT14
14      FORMAT(' TYPE RECEIVER CENTER FREQUENCY')
        READ15,FQRCVR
15      FORMAT(F13.6)
        FREQ(20)=FQRCVR
        PRINT 158
158     FORMAT('  TYPE 3/2 K3/K1 IN DB ')
        READ 159,RK3K1
159     FORMAT(F13.6)
         LDEX=1
C       SETTING RECEIVER BANDWIDTH IN KHZ
        BW=40.
C
C.... ENTERING EDIT MODE ....
3999    CALL CHANGE(JUMP)
        GO TO (4000,4000,4001,4002),JUMP
C
C.... CALCULATING SIGNAL LEVELS AT RF AND INPUT ....
```

```
C
4000  CALL MILEDB
C
C.... CALCULATING BRUTE FORCE INTERFERENCE ....
C
4001  CALL XMOD
C
C.... ENTERING EDIT MODE ....
C
      CALL CHANGE (JUMP)
      GO TO (4003,4000,4001,4002),JUMP
4003  CONTINUE
C
C
C
C.... PRINTOUT OF INTERMOD GENERATING FREQUENCIES ....
C
C
C
C     PRINTING OF HEADINGS
C
C
      CALL TEST(0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,FRRCVP,BW,ITEST,2,
     C      RK3K1)
C
C
C
C     TEST IS PERFORMED TO SEE IF INTERMOD SPECTRUM PRODUCED
C     BY THREE FREQUENCIES WILL GIVE A CONTIBUTION AT THE
C     RECEIVER FREQUENCY
C
C
C
      DO 520 I=1,NSTAT
      DO 521 J=I,NSTAT
      DO 522 K=1,NSTAT
C
C
C
C     SUBROUTINE TEST PRINTS OUT FREQUENCIES WHICH GENERATE INTERMOD
C     WITHIN THE RECEIVER BW
C
C
C
C
      CALL TEST(FREQ(I),FREQ(J),FREQ(K),FMOD(I),FMOD(J),FMOD(K),
     C BETA(I),BETA(J),BETA(K),LEVEL(I),LEVEL(J),LEVEL(K),FRRCVP,BW,
     CITEST,1,RK3K1)
C
C
C
522   CONTINUE
521   CONTINUE
520   CONTINUE
C
```

```
C
4002  CONTINUE
      PRINT 577
577   FORMAT (///'  TO CALCULATE INTERMOD SPECTRUM TYPE 0 ,TYPE 1 TO STO
     CP, TYPE 2 TO RESTART PROGRAM',/,'  TYPE 3 TO CHANGE PARAMETERS AND
     C RECALCULATE INTERFERENCE')
       READ 17, ICALC
17    FORMAT(I1)
      IF(ICALC.EQ.3)GO TO 3999
      IF(ICALC-1)109,110,1
C
C
C.... CALCULATION OF INTERMOD ....
 109  CALL IMCALC
      PRINT 1009
1009  FORMAT(//,1X,72('*'),//)
      PRINT 1100
1100  FORMAT('  TO STOP TYPE 0, TO MODIFY PARAMETERS TYPE 1,FOR ',
     C 'TOTAL RESTART TYPE 2 ')
      READ 17, ICALC
      IF(ICALC-1)110,3999,1
110     STOP
       END
C=====================================================================
C=====================================================================
C=====================================================================
C=====================================================================
C*********************************************************************
C
      SUBROUTINE TEST(FREQ1,FREQ2,FREQ3,FMOD1,FMOD2,FMOD3,BETA1,BETA2,
     C          BETA3,RLEV1,RLEV2,RLEV3,FQRCVR,BW,ITEST,IPRINT,RK3K1)
C******************************************************************
C
C     THIS SUBROUTINE TESTS FM FREQS :FREQ1,FREQ2,FREQ3 TO SEE
C     IF THE F1+F2-F3 IM IS WITHIN THE RECEIVER BW WITH RECEIVER
C     FREQ:FQRCVR. IF THERE IS ,ITEST SET TO 1,OTHERWISE SET TO 0
C     WHEN IPRINT=2 ,PRINTS OUT HEADINGS
C
C
      ITEST=1
C     SUMLEV IS THE NO MODULATION INTERMOD LEVEL;6 DB IS ADDED IF
C     FREQ1 IS NOT THE SAME AS FREQ2
      SUMLEV=RLEV1+RLEV2+RLEV3+RK3K1
      IF(FREQ1.NE.FREQ2)SUMLEV=SUMLEV+6.
       IF(IPRINT-1)2,2,1
C
C     PRINTING OF HEADINGS WHEN IPRINT=2
C
C
C
1      PRINT600, FQRCVR,BW
600   FORMAT (////,'  RECEIVER FREQUENCY IS ',F6.2,' RECEIVER BANDWIDTH
     C IS ',F6.1,'  KHZ')
      PRINT 601
601   FORMAT ('  FREQUENCIES WHICH PRODUCE INTERMOD INTERFERENCE ARE:')
```

```
      PRINT 602
602   FORMAT(3X,'F1',6X,'F2',6X,'F3',8X,'IM TYPE',2X,'IM CENTER FREQ',
     C   2X,'IM BW IN KHZ      IM LEVEL IN DBM,NO FM STAT. MODULATION',/)
C
      RETURN
C
C
C
C
C     TEST IS PERFORMED TO SEE IF INTERMOD SPECTRUM PRODUCED
C     BY THREE FREQUENCIES WILL GIVE A CONTIBUTION AT THE
C     RECEIVER FREQUENCY
C
C
C
C     FMIN IS THE MIN FREQ OF INTERMOD
C     FMAX IS MAXIMUM
C     RULE OF THUMB FOR THE BANDWIDTH OF A FM SIGNALIS USED TO
C     CALCULATE WHETHER INTERMOD IS WITHIN RECEIVER PASSBAND
C     ROT:BW=2*FREQMODULATING(1+MODULATION INDEX)
C
C
C
C
C     TEST TO SEE IF INTERMOD IS GENERATED WITHIN RECEIVER BW
2      DELTA=FMOD1*(1.+BETA1)+FMOD2*(1.+BETA2)+FMOD3*(1.+BETA3)
      FFMIN=FREQ1+FREQ2-FREQ3-FQRCVR
      FFMAX=FFMIN
C      FMIN AND FMAX ARE CONVERTED TO KHZ
      FMIN=FFMIN*1000.-DELTA
      FMAX=FFMAX*1000.+DELTA
C     CHECK TO SEE IF FMIN OR FMAX FALLS WITHIN RECEIVER BW
      IF(ABS(FMAX).LT.(BW/2.).OR.ABS(FMIN).LT.(BW/2.))GO TO 5200
C     CHECK TO SEE IF INTERMOD SPANS ENTIRE RCVR BW
      IF(FMIN.LT.(-BW/2.).AND.FMAX.GE.(BW/2.)) GO TO 5200
      GO TO 5202
5200     FSUM=FREQ1+FREQ2-FREQ3
      FBW=DELTA*2.
        IF(FREQ1.NE.FREQ2.AND.IPRINT.EQ.1)PRINT23,FREQ1,FREQ2,FREQ3,FSU
     CM,FBW,SUMLEV
23    FORMAT(3F8.1,5X,' F1+F2-F3 ',5X,F7.2,3X,F5.0,15X,F6.1)
C
C
      IF(FREQ1.EQ.FREQ2.AND.IPRINT.EQ.1)PRINT 5201,FREQ1,FREQ3,FSUM,FBW
     C ,SUMLEV
5201  FORMAT(2F8.1,10X,'     2F1-F2     ',5X,F6.2,3X,F5.0,15X,F6.1)
C
      RETURN
C  IM IS NOT IN THE RECEIVER BW
5202  ITEST=0
      RETURN
      END
C
C
C*****************************************************************
```

```
C
      SUBROUTINE XMOD
C
C*************************************************************************
C
C     THIS SUBROUTINE CALCULATES THE AMT OF CROSS MODULATION DUE
C     TO INTERFERING FM STATIONS.ALSO COMPUTES THE AMT OF CROSS
C     COMPRESSION.
C
        DIMENSION FREQ(20),FMOD(20),BETA(20)
C
      REAL MILE(20),POWER(20),FQDEV(20)
      REAL LEVEL(20)
C
      COMMON FQRCVR,XMOD1,XMOD2,XMOD3,XMOD4,SUMC,BW,RK3K1
      COMMON FREQ,LEVEL,FMOD,BETA
      COMMON MILE,POWER,FQDEV,NSTAT
C
C
C
C
C     IF THE AM MODULATION IS TO COMPUTED USING THE FREQUENCIES OF MODUL
C     MODULATION SPECIFIED BEFORE ,DELTA F CALCULATIONS ARE MADE
C
C
C
      PRINT1
1     FORMAT('  TO USE MAXIMUM FREQUENCY DEVIATION SPECIFIED BY MODULA'
     C ,'TION FREQUENCY ',/,'   AND MODULATION INDEX TYPE 1,  OTHERWISE
     C FQDEV(I) MUST BE SPECIFIED')
      READ 51,IFLAG
51     FORMAT(I1)
C
C
C
C
C     .....PRINTING OF HEADINGS   ................
C
C
      PRINT 20
20    FORMAT('   *********CROSS MODULATION CALCULATIONS ***********')
      PRINT 21
21    FORMAT('  STATION  COMPRESSION     FREQ DEV.   % AMMOD',/,
     C'  FREQ      OF LOC.SIGNAL    FOR XMOD    CAUSED',/,
     C'   (MHZ)    IN DB            CALC.(KHZ)  BY STAT.',/)
C
C
C
C     ..............FOR EACH STATION CALCULATING CROSSMODULATION
C
C
C     VARIABLE NAMES:
C
C
C     CROSSL-LINEAR COMPRESSION FACTOR FOR ONE STATION ONLY(ITH STATION)
```

```
C             I.E.3 K3/K1 B**2 WHERE B IS THE SIGNAL LEVEL OF THE ITH
C             STATION AT THE RF AMP INPUT.
C       PERCNT- % CROSSMOD OF LOCALIZER SIGNAL DUE TO STATION I,CROSS
C            COMPRESSION NOT CONSIDERED
C       PERCOM- % AM MOD DUE TO STATION I CONSIDERING CROSSCOMPRESSION
C       SUMC-COMPRESSON FACTOR DUE TO ALL STATIONS.(RESULTANT LOC. LEVEL
C            IS MULTIPLIED BY (1-SUMC)
C       SUMCDB-COMPRESSION OF LOC. SIGNAL DUE TO ALL FM STAT.EXPRESSED IN
C           DB.I.E. SUMCDB=20 LOG (1-SUMC)
C       XMOD1-TOTAL % RMS AM MOD AT THE DETECTOR OUTPUT DUE TO
C           CROSSMOD FROM ALL STAT.(IT INCLUDES EFFECTS OF
C            CROSSCOMPRESSION ONLY IF SUMC IS LESS THAN 1
C       XMOD2-% RMS AM MOD AT THE RECEIVER AUDIO OUTPUT
C       XMOD3-% RMS AM MOD AT 150 HZ FILTER OUTPUT OF RECEIVER
C       XMOD4- % RMS AM MOD AT 90 HZ FILTER OUT
C
C
C
        TOTAL=0.
        XMOD1=0.
        XMOD2=0.
        XMOD3=0.
        XMOD4=0.
        SUMC=0.
        DO 50 I=1,NSTAT
C
C
C
C
C       COMPUTATION OF THE CROSS COMPRESSION DUE TO THE I TH STATION,IN DB
C
C
C
        CROSS=RK3K1+2.*LEVEL(I)+6.
C
C
C       CONVERTING FROM DB TO LINEAR
        CROSSL=10.**(CROSS/20.)
C
C       CALCULATION OF DB COMPRESSION OF LOCALIZER SIGNAL IN DB DUE TO
C       STATION I
C       SETING COMPES TO A LARGE VALUE TO PRINT ASTERISKS WHEN G.T. 1.
        COMPES=1000.
        IF((1.-CROSSL).GT.0.)COMPES=-20.*ALOG10(1.-CROSSL)
C
C
C       SUMMING CROSS COMPRESSION DUE TO ALL STATIONS
        SUMC=SUMC+CROSSL
C
C
C       CALCULATING MAX FREQ DEVIATION FROM DEFINITION OF BETA,IF NOT READ
C       IN FROM ABOVE
C
C
C
```

```
      IF(IFLAG.EQ.1)FQDEV(I)=BETA(I)*FMOD(I)
C
C
C     THE RF AMP INPUT FILTER SLOPE IS APPROXIMATED TO BE .15DB /100KHZ
C     FOR FREQS LESS THAN 8 MHZ FROM RECEIVER FREQ.,.075DB /100KHZ
C     OTHERWISE   * REVISED JUNE 78
C
C     COMPUTATION OF SLOPE
      SLOPE=((2.302)/20.)*(.15/100.)*10**(-((FQRCVR-FREQ(I))*1.5/20.))
      IF((FQRCVR-FREQ(I)).GT. 8.) SLOPE=.2511*(.075/100.)*(2.303/20.)*
     C 10**(-((-8.+FQRCVR-FREQ(I))*.75/20.))
C     CALCULATION OF PERCENT CROSS MOD DUE TO STATION I
C
C
      PERCNT=SLOPE*FQDEV(I)*2.*CROSSL*100.
C
C
C     SUMMING RMS AM MOD DUE TO ALL STATIONS
C
C
C     TOTAL IS THE UNFILTERED TOTAL % AM MOD
      TOTAL=PERCNT**2+TOTAL
C
C
C
C     CALCULATING THE RMS % AM MOD AT THE OUTPUT OF THE RECEIVER
C     FILTERS
C
C
      XMOD1=XMOD1+(PERCNT*FILDET(FMOD(I)))**2
      XMOD2=XMOD2+(PERCNT*FILAUD(FMOD(I)))**2
      XMOD3=XMOD3+(PERCNT*FIL150(FMOD(I)))**2
      XMOD4=XMOD4+(PERCNT*FIL90(FMOD(I)))**2
C     CALCULATION OF PERCENT MODULATION CONSIDERING CROSS COMPRESSION
C     DUE TO STATION I
      PERCOM=PERCNT/(1.-CROSSL)
C
50    PRINT 100,FREQ(I),COMPES,FQDEV(I),PERCOM
100   FORMAT(3X,F5.1,5X,F5.1,10X,F4.0,7X,F5.2)
C
C
C................. CALCULATIONS OF TOTAL CROSSMOD .....................
C
C
C
C     IF SUMC (THE TOTAL COMPRESSION OF LOC. SIGNAL DUE TO ALL STATIONS)
C     IS GREATER THAN 1 THIRD ORDER MODEL OF RECEIVER DOES NOT APPLY
C
      IF((1.-SUMC).LT.0.)GO TO 300
       SUMCDB=-20.*ALOG10(1.-SUMC)
      GO TO 310
300   PRINT301
301   FORMAT('  ****CROSS COMPRESSION GREATER THAN 1 ,THIRD ORDER ',
     C 'MODEL OF RECEIVER NO LONGER VALID   *******')
C
```

```
C
C       SETTING DUMMY VALUE FOR TOTAL COMPRESSION.I.E. SUMCDB
C       TO PRINT ASTERISKS WHEN SUMCDB IS PRINTED
C
C
        SUMCDB=-10000.
C
C
C       CALCULATING TOTAL MODULATION IN PERCENT ,CONSIDERING COMPRESSION
C       OF THE DESIRED SIGNAL
C
C
C
310     SUMM=SQRT(TOTAL)/(1.-SUMC)
        PRINT400,TOTAL,SUMC,SUMCDB,SUMM
400     FORMAT(' TOTAL PERCENT MOD.,NOT CONSIDERING CROSSCOMPRESSION='.
       C F5.2,/,' COMPRESSION FACTOR= ',F5.3,/,' LOCALIZER SIGNAL COMPRESS
       CION IN DB=',F7.1,/,'  TOTAL % RMS UNFILTERED  AM MODULATION= ',F5.
       C2)
C       ...........TOTAL % FILTERED AM MOD CALCULATIONS...............
C
C
C       IF THE TOTAL CROSSCOMPRESSION DUE TO ALL STATIONS IS GREATER
C       THAB 1,THEN THE EFFECTS OF CROSS COMPRESSION ARE NOT INCLUDED
C       IN THE % AM MOD CALCULATIONS,OTHERWISE IT IS CONSIDERED.
C
C
        C=1.
        IF(SUMC.LT.1.)C=1.-SUMC
C
C
        XMOD1=SQRT(XMOD1)/C
        XMOD2=SQRT(XMOD2)/C
        XMOD3=SQRT(XMOD3)/C
        XMOD4=SQRT(XMOD4)/C
C       PRINTOUT OF THE TOTAL AMOUNT OF AM MODULATION
C
C
C
        PRINT 3000
3000    FORMAT(//,1X,72('*'),/,3X,'TOTAL RMS AM MODULATION',
       C /,3X,'DUE TO CROSSMOD INTERFERENCE' )
        IF(SUMC.LT.1.)PRINT3005
3005    FORMAT(3X,'CROSSCOMPRESSION EFFECTS INCLUDED',/)
        IF(SUMC.GE.1.)PRINT 3006
3006    FORMAT(3X,'CROSSCOMPRESSION EFFECTS NOT INCLUDED',/)
        PRINT 3001,XMOD1
        PRINT 3002,XMOD2
        PRINT 3003,XMOD3
        PRINT 3004,XMOD4
3001    FORMAT(3X,'DETECTOR OUTPUT AM MODULATION:',F4.1,' %',/)
3002    FORMAT(3X,'    AUDIO OUTPUT AM MODULATION: ',F4.1,' %',/)
3003    FORMAT(3X,'150 HZ FILTER OUTPUT AM MODULATION: ',F4.1,' %',/)
3004    FORMAT(3X,' 90 HZ FILTER OUTPUT AM MODULATION: ',F4.1,' %',/)
        RETURN
```

```
      END
C*****************************************************************************
      SUBROUTINE MILEDB
C*****************************************************************************
C     THIS SUBROUTINE CONVERTS THE DISTANCE FROM THE FM STATION
C     TO SIGNAL LEVELIN DBM AT THE RFAMP INPUT.
C     THE PROGRAM TAKES INTO ACCOUNT THE RF AMP FILTER CHARACTERISTICS
C     AND THE ATTENUATION OF THE NAV ANTENNA .
C      USES FREE SPACE ATTENUATION FORMULA
C
      DIMENSION FREQ(20),FMOD(20),BETA(20)
      REAL LEVEL(20)
      REAL MILE(20),POWER(20),FODEV(20)
C
      COMMON FORCVR,XMOD1,XMOD2,XMOD3,XMOD4,SUMC,BW,RK3K1
      COMMON FREQ,LEVEL,FMOD,BETA
      COMMON MILE,POWER,FODEV,NSTAT
      PRINT 5
5     FORMAT(' TO  COMPUTE SIGNAL LEVEL AT RF AMP INPUT TYPE 1'
     C,/,' OTHERWISE VALUES OF LEVEL(I) MUST BE INITIALIZED IN THE  '
     C,/,' EDIT MODE AND USED AS THE SIGNAL LEVEL AT THE RF AMP INPUT')
C
      READ 6,IFLAG
6     FORMAT(I1)
      IF (IFLAG .NE.1)RETURN
      PRINT 40
40    FORMAT('  PRINTOUT OF SIGNAL LEVEL COMPUTATIONS',/)
      PRINT 41
41    FORMAT(' STATION  MILES     STATION  FREE     NAV      RCVR IN',
     C  'PUT SIGNAL',/,'  FREQ     FROM      POWER    SPACE     AN',
     C 'TENNA  FILTER     LEV AT ')
      PRINT 42
42    FORMAT('   (MHZ)   RECEIVER  IN DBM   ATTEN-DB LOSS-DB  ATTEN DB',
     C '   RFAMP IN (DBM)',/)
      DO 50 I=1,20
      IF(I.GT.NSTAT.AND.I.NE.20)GO TO 50
C     FREE SPACE ATTENUATION COMPUTATION
43    ATTEN=36.6+20.*ALOG10(FREQ(I))+20.*ALOG10(MILE(I))
      RPOWER=60.+10.*ALOG10(POWER(I))
C        COMPUTATION OF LOSS DUE TO ANTENNA CHARACTERISTICS 1 DB PER MHZ
C     BELOW 108.5MHZ
      ALOSS=0.
      IF(FREQ(I).LT.108.5)ALOSS=108.5-FREQ(I)
      RFLOSS=RFFILT(FORCVR,FREQ(I))
C     6 DB GAIN IS ADDED FOR DIRECTIVE GAIN OF NAV ANTENNA
      LEVEL(I)=RPOWER-ATTEN-ALOSS-RFLOSS+6.
      IF(I.EQ.20)PRINT 700
      PRINT 100,FREQ(I),MILE(I),RPOWER,ATTEN,ALOSS,RFLOSS,LEVEL(I)
100   FORMAT(2X,F5.1,4X,F4.1,6X,F5.1,3X,F5.1,2(4X,F5.1),6X,F5.1)
50    CONTINUE
700   FORMAT(/,'  LOCALIZER SIGNAL LEVEL CALCULATIONS:',/)
       RETURN
      END
C*********************************************************************
      REAL FUNCTION RFFILT(FRQRCV,FMFREQ)
```

```
C**********************************************************************
C      THIS FUNCTION COMPUTES  THE ATTENUATION OF THE RF AMP INPUT FILTER
C      FOR THE NAV 11 RECEIVER * REVISED JUNE 78
       RFFILT=0.0
       DELTA=FRORCV-FMFREQ
       IF(DELTA.LT.0.) RETURN
       IF(DELTA.GT.8.)GO TO 10
       RFFILT= 1.5*DELTA
       RETURN
10     RFFILT=12.+(DELTA-8.)*.75
       RETURN
       END
C**********************************************************************
        SUBROUTINE CHANGE(JUMP)
C**********************************************************************
C
C
C       THIS PROGRAM MAKES CHANGES IN PROGRAM PARAMETERS
C
C
        REAL NAME(15)/'FREQ','FMOD','BETA','LEVE','MILE','POWE',
      C 'FQDE','INST','TYPE','STOP','MXD5','XMOD','/','IM  ','CONT'/
C
          DIMENSION FREQ(20),FMOD(20),BETA(20)
C
        REAL MILE(20),POWER(20),FQDEV(20)
        REAL LEVEL(20)
C
        COMMON FQRCVR,XMOD1,XMOD2,XMOD3,XMOD4,SUMC,BW,FK3K1
        COMMON FREQ,LEVEL,FMOD,BETA
        COMMON MILE,POWER,FQDEV,NSTAT
C
C
C
C       PARAMETER JUMP IS RETURNED WITH A VALUE WHICH TELLS WHERE PROGRAM
C       CONTROL IS TO BE TRANSFERRED  . JUMP=1 IS NORMAL RETURN.
C
        JUMP=1
        PRINT 7
7       FORMAT ('   ***  PROGRAM PARAMETER EDIT MODE   ***',/,
      C '    FOR INSTRUCTIONS TYPE: INST ',/)
C
C
C       READ IN OF COMMAND
C
1       READ11,PARA,N,X
11      FORMAT(A4,1X,I2,F13.6)
        IF(PARA.EQ.NAME(10)) GO TO 99
C
C
C       IFLAG IS SET TO 1 WHEN N =0.
C
        IFLAG=0
        IF(N.EQ.0.0)IFLAG=1
        IF(N.EQ.0.0)N=1
```

```
C
C
C      DETERMINING WHICH COMMAND IS READ IN BY COMPARING PARA TO NAME(I)
C
C
       DO 20 I=1,15
       IF(PARA.EQ.NAME(I))GO TO 30
 20    CONTINUE
       PRINT 21
21     FORMAT(    '  ERROR IN INSTRUCTION ,RETYPE   ')
       GO TO 1
C
C
C      CONTROL IS TRANSFERRED TO THE PROPER STATEMENT ACCORDING TO
C      THE INPUTTED COMMAND
C
C
C
30     GO TO (41,42,43,44,45,46,47,48,49,50,51,52,53,54,55),I
41     FREQ(N)=X
       GO TO 2
42     FMOD(N)=X
       GO TO 2
43     BETA(N)=X
       GO TO 2
44     LEVEL(N)=X
       GO TO 2
45     MILE(N)=X
       GO TO 2
46     POWER(N)=X
       GO TO 2
47     FQDEV(N)=X
       GO TO 2
48     PRINT 481
       PRINT 482
       GO TO 1
49      IF(IFLAG.EQ.1.AND.N.EQ.1.OR.IFLAG.EQ.0)GO TO 495
       GO TO 496
495    PRINT 491
491    FORMAT(' STATION  STATION  MODULATION  MODULATION  MAX FREQ   LEVE
      CL       MILES       STATION')
       PRINT 492
492    FORMAT(' NUMBER   FREQ     FREQ (KHZ)  INDEX        DEVIATION  AT R
      CF AMP  FROM        POWER-ERP')
       PRINT 493
493     FORMAT(10X,'(MHZ)',27X,'(XMOD CALC) INPUT=DBM   RECEIVER',
      C  '  (KW)')
496    PRINT 100,N,FREQ(N),FMOD(N),BETA(N),FQDEV(N),LEVEL(N),
      C  MILE(N),POWER(N)
100     FORMAT(3X,I2,5X,F5.1,5X,F6.3,5X,F6.2,7X,F5.1,6X,F5.1,4X,F5.1,7X,F
      C7.2)
       GO TO 2
50     GO TO 99
51      JUMP=2
        GO TO 99
```

```
52     JUMP=3
       GO TO 99
53     JUMP=1
       GO TO 99
54     JUMP=4
       GO TO 99
55     JUMP=1
       GO TO 99
C
C
C      IF IFLAG =1 THEN THE COMMAND IS REPEATED FOR EACH STATION
C      (EXCEPT FOR STATION NO.20 I.E. LOCALIZER)
C
C
2      IF(IFLAG.EQ.0)GO TO 1
       N=N+1
       IF(N.GT.NSTAT)GO TO 1
       GO TO 30
C
C
C
C      TYPING OF INSTRUCTIONS
C
C
481    FORMAT(/,' IN PARAMETER EDIT MODE ALL COMMANDS ARE TYPED AS:',//,
      C' XXXXXNNYYYYYYYYYYY',//,' WHERE XXXXX IS THE COMMAND',
      C /,' NN IS THE STATION NUMBER',/,' YYYYYYYYYYY IS THE PAR',
      C'AMETER FIELD(FORMAT F13.6)',//,' IF NN IS 00 THEN ALL '
      C,'STATIONS ARE AFFECTED EXCEPT FOR STATION NO 20'
      C ,/,' WHICH IS THE STATION CODE NUMBER GIVEN TO THE LOCALIZER'
      C,/,' EACH FM STATION HAS A STATION NO.(INPUT TYPE 00 FOR',
      C /,' THE STATION NUMBERS)',///,'  POSSIBLE COMMANDS:',//,
      C' INST-PRINTS OUT THESE INSTRUCTIONS',/,' TYPE NN- PRINTS OUT',
      C'  PARAMETERS FOR STATION NN',/,' STOP - ENDS EDIT MODE',/,
      C' /        - ENDS EDIT MODE ',/,' CONT- ALSO ENDS EDIT MODE',/,
      C' FREQ NNYYYY - CHANGES STATION NN FREQUENCY TO YYYY MHZ',/,
      C' FMOD NNYYYY - CHANGES MODULATION FREQUENCY OF STAT. NN TO ',
      C'YYYY',/,' BETA NNYYYY - CHANGES THE MODULATION INDEX OF '
      C,'STATION NN TO YYYY',/,
      C' MILE NNYYYY - CHANGES THE DISTANCE FROM THE RECEIVER OF'
      C,' STAT. NN TO YYYY MILES',/,' LEVELNNYYYY - CHANGES THE SIGNAL LE
      CVEL DUE TO STAT. NN AT RECEIVER INPUT  TO YYYY DBM')
482    FORMAT(' POWERNNYYYY - CHANGES STATION NN POWER LEVEL TO YYYY KWAT
      CTS',/,' FDDEVNNYYYY - CHANGES FREQUENCY DEVIATION OF STAT. NN TO'
      C ,' YYYY KHZ (ONLY USED IN CROSSMOD CALC.)',/,
      C' MXDH - TRANSFERS PROGRAM CONTROL FROM EDIT MODE',
      C         ' TO CALCULATE SIGNAL LEVELS FROM DISTANCE TO RECEIVER'
      C,/,' IM      - INTERMOD INTERFERENCE IS CALCULATED',/,
      C' XMOD - CALCULATIONS OF CROSSMOD INTERFERENCE ARE MADE',//,
      C' ***  ENTER INSTRUCTION  ***',/)
99     RETURN
       END
```

```
C*****************************************************************************
      SUBROUTINE IMCALC
C
C
C*****************************************************************************
C     THIS SUBROUTINE CALCULATES THE AM MODULATION DUE TO INTERMOD
C     INTERFERENCE
C
C     IMCALC CHECKS ALL COMBINATIONS OF 3 STATIONS (STATIONS I,J,K )
C     TO SEE IF THE 3RD ORDER INTERMOD CAUSES INTERFERENCE AT
C     AT THE RECEIVER FREQUENCY. THIS IS DONE BY CALLING SUBROUTINE TEST
C     WHICH  CHECKS THE 3 FREQS AND RETURNS WITH ITEST=1 IF THEY PRODUCE
C     INTERFERING  IM. SUBROUTINE CONVOL IS CALLED WHICH DOES THE
C     CONVOLUTION OF THE 3 FM SPECTRA AND RETURNS WITH THE MODULATION
C     FACTORS OF THE RECEIVER FILTER OUTPUTS( CALLED SUMDET,SUMAUD,
C     SUM150,SUM90). IMCALC USES THE MODULATION FACTORS TO CALCULATE THE
C     % RMS AM MODULATION AT  THE FILTER OUTPUTS.(CALLED PER1,PER2,
C     PER3,PER4 ). TOTAL % AM MODULATION DUE TO THE IM FROM ALL
C     INTERFERRING STATIONS IS SUMMED.(CALLED TOTAL1,TOTAL2, ETC. )
C     THE CDI WITH INTERFERENCE IS CALCULATED BY CALLING SUBROUTINE CDI.
C     THE ABOVE CALCULATIONS DO NOT CONSIDER EFFECTS OF BRUTE FORCE
C     INTERFERENCE.THE COMBINED EFFECTS OF CROSS MOD,CROSS COMPRESSION,
C     AND INTERMOD ARE ADDED AND PRINTED OUT. CDI CALCULATIONS ARE
C     AGAIN MADE.
C
C
C
C
C
      DIMENSION FREQ(20),FMOD(20),BETA(20)
      REAL MILE(20),POWER(20),FQDEV(20)
      REAL LEVEL(20)
C
      COMMON FQRCVR,XMOD1,XMOD2,XMOD3,XMOD4,SUMC,BW,PK3K1
      COMMON FREQ,LEVEL,FMOD,BETA
      COMMON MILE,POWER,FQDEV,NSTAT
C
      PRINT 10
C
C
C
C
C     IM % AM MOD VARIABLE NAMES:
C
C
C     TOTAL1 IS  THE TOTAL % RMS AM MOD DUE TO ALL FM STATIONS
C             AT THE OUTPUT OF THE DETECTOR FILTER
C     TOTAL2 IS % AT THE AUDIO OUTPUT.
C     TOTAL3 IS THE %  AT THE 150 HZ OUTPUT
C     TOTAL4 IS THE % AT THE 90HZ FILTER OUTPUT.
C
C     PER1 IS THE % AM MOD DUE TO IM FROM STATIONS I,J,K ONLY AT
C        THE DETECTOR FILTER OUTPUT.
C     PER2 IS THE % AM MOD DUE TO STAT. I,J,K AT THE AUDIO OUTPUT.
C     PER3 IS THE % AM MOD AT THE 150 HZ FILTER OUTPUT.
```

```
C       PER4 IS THE % AM MOD AT THE 90 HZ OUTPUT
C
C
C
        TOTAL1=0.
        TOTAL2=0.
        TOTAL3=0.
        TOTAL4=0.
C
C
C
C
C>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
C
C
C
        DO 520 I=1,NSTAT
        DO 520 J=I,NSTAT
        DO 520 K=1,NSTAT
C
C
C
C
C
C       TEST IS PERFORMED TO SEE IF INTERMOD SPECTRUM PRODUCED
C       BY THREE FREQUENCIES WILL GIVE A CONTIBUTION AT THE
C       RECEIVER FREQUENCY
C
C
C
C
C       SUBROUTINE TEST DETERMINES WHICH FREQUENCIES PRODUCE INTERMOD
C       INTERFERENCE WITHIN THE RECEIVER BANDWIDTH;
C       IF THERE IS INTERMOD ,SUBROUTINE CONVOL- THE CONVOLUTION
C       SUBROUTINE - IS CALLED.
C
C
C
C
        CALL TEST(FREQ(I),FREQ(J),FREQ(K),FMOD(I),FMOD(J),FMOD(K),
       C BETA(I),BETA(J),BETA(K),LEVEL(I),LEVEL(J),LEVEL(K),FORCVR,BW,
       CITEST,0,FK3K1)
         IF( ITEST .EQ.0)GO TO 520
C
C
C       CALLING OF CONVOLUTION SUBROUTINE TO CALCULATE RMS AM MODULATION
C       SUBROUTINE CONVOL RETURNS WITH THE MODULATION FACTORS FOR THE
C       DETECTOR ,AUDIO,90,AND 150HZ FILTER OUTPUTS.
C
C
        CALL CONVOL(I,J,K,SUMDET,SUMAUD,SUM90,SUM150)
C
C
C
C       PRINTOUT OF AM MOD
```

```
C
10    FORMAT(/,1X,72('*'),/,3X,'INTERMOD AM MODULATION CALCULATIONS:')
      PRINT 11
11    FORMAT(/,1X,72('.'),/,'  CALCULATION PARAMETERS :',/)
      IF(I.EQ.J)PRINT12
12    FORMAT( '  INTERMOD TYPE: 2F1-F2',/)
      IF(I.NE.J)PRINT13
13    FORMAT( '  INTERMOD TYPE: F1+F2-F3',/)
      PRINT 15
15    FORMAT(3X,' STATION FREQ    MODULATION   MODULATION',/,3X
     C, '    (MHZ)',8X,'FREQ (KHZ)',5X,'INDEX',/)
C
C
C
      IF(I.EQ.J)GO TO 161
      JJ=1
      PRINT 16,JJ,FREQ(I),FMOD(I),BETA(I)
      JJ=2
      PRINT 16,JJ,FREQ(J),FMOD(J),BETA(J)
      JJ=3
      PRINT 16,JJ,FREQ(K),FMOD(K),BETA(K)
      GO TO 200
C     PRINTOUT FOR 2F1-F2 INTERMOD
161   JJ=1
      PRINT 16,JJ,FREQ(I),FMOD(I),BETA(I)
      JJ=2
      PRINT 16,JJ,FREQ(K),FMOD(K),BETA(K)
16    FORMAT(3X,'F',I1,':',2X,F5.1,8X,F7.3,7X,F6.1)
200   CONTINUE
C
C
C     CALCULATIONS OF % MODULATION
C
C     RIMLEV IS THE CARRIER LEVEL OF THE INTERMOD IN DBM
C
      RIMLEV=LEVEL(I)+LEVEL(J)+LEVEL(K)+RK3K1
C     ADD 6 DB TO THE CARRIER LEVEL IF INTERMOD IS F1+F2-F3 TYPE
      IF(I.NE.J)RIMLEV=RIMLEV+6.
      PRINT210,RIMLEV
210   FORMAT(//,3X,'INTERMOD LEVEL (NO FM STATION MODULATION)=',F6.1,'
     CBM')
      PRINT 220,SUMDET
220   FORMAT(//,3X,'DETECTOR MODULATION FACTOR= ',F5.3)
      PRINT2201,SUMAUD
2201  FORMAT(/,3X,'AUDIO OUTPUT MODULATION FACTOR= ',F5.3)
      PRINT2202,SUM150
2202  FORMAT(/,3X,'150 HZ FILTER MODULATION FACTOR= ',F5.3)
      PRINT2203,SUM90
2203  FORMAT(/,3X,' 90 HZ FILTER MODULATION FACTOR= ',F5.3,/)
C
C
C
C
C     % CALCULATION KNOWING LOCALIZER SIGNAL LEVEL
C
```

```
C
C       CALCULATION OF THE MODULATION INDEX OF THE IM CARRIER
C       BY COMPARING ITS LEVEL TO THE LOCALIZER LEVEL,CONVERTING FROM DBM
        PERMOD=100.*(10.**((-LEVEL(20)+RIMLEV)/20.))
C
C
C
C       USING THE MODULATION FACTOR TO CALCULATE THE % MODULATION FOR FM
C       MODULATED INTERFERENCE.
C
C
        PER1=PERMOD*SUMDET
        PER2=PERMOD*SUMAUD
        PER3=PERMOD*SUM150
        PER4=PERMOD*SUM90
C       SUMMING TOTAL INTERFERENCE
C
C
C
C
C
C       TOTAL1 IS THE TOTAL RMS MODULATION DUE TO INTERMOD AT THE DETECTOR
C       OUTPUT.TOTAL2 IS THE % AM MOD AT THE AUDIO OUTPUT;TOTAL3 AT THE
C       150 HZ OUTPUT; TOTAL4 AT THE 90 HZ OUTPUT.
        TOTAL1=TOTAL1+(PER1)**2
        TOTAL2=TOTAL2+(PER2)**2
        TOTAL3=TOTAL3+(PER3)**2
        TOTAL4=TOTAL4+(PER4)**2
C
C
C
        PRINT 1000,PER1
1000    FORMAT(3X,'RMS AM MODULATION AT DETECTOR OUTPUT= ',F4.1,' %')
        PRINT 1001,PER2
1001    FORMAT(/,3X,'RMS AM MODULATION AT AUDIO OUTPUT= ',F4.1,' %')
        PRINT1002,PER3
1002    FORMAT(/,3X,'RMS AM MODULATION AT 150 HZ FILTER OUTPUT= ',F4.1,
       C ' %')
        PRINT1003,PER4
1003    FORMAT(/,3X,'RMS AM MODULATION AT  90 HZ FILTER OUTPUT= ',F4.1,
       C ' %')
520     CONTINUE
C
C
C
C>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
C
C
C
C
C
C
        PRINT 521
521     FORMAT(/,1X,72('*'),//,'  FOR PRINTOUT OF TOTAL INTERFERENCE TYPE
       C1')
```

```
      READ 522,IPRINT
522   FORMAT(I1)
      IF(IPRINT.NE.1)RETURN
C
C
C
      TOTAL1=SQRT(TOTAL1)
      TOTAL2=SQRT(TOTAL2)
      TOTAL3=SQRT(TOTAL3)
      TOTAL4=SQRT(TOTAL4)
C     PRINTOUT OF THE TOTAL AMOUNT OF AM MODULATION
C
C
C
C
C     IFLAG IS SET TO 1 TO INDICATE THAT INTERFERENCE CALCULATIONS
C     DUE TO IM ONLY
C
      IFLAG=0
2999  PRINT 3000
3000  FORMAT(//,1X,72('*'),/,3X,'TOTAL RMS AM MODULATION',
     C /,3X,'DUE TO INTERMOD INTERFERENCE')
      IF(IFLAG.EQ.1)PRINT 2998
2998  FORMAT(3X,'AND BRUTE FORCE INTERFERENCE',/,
     C3X,'CROSS COMPRESSION EFFECTS CONSIDERED',/)
      IF(IFLAG.EQ.0)PRINT 2997
2997  FORMAT(3X,'CROSS COMPRESSION EFFECTS NOT CONSIDERED',/)
      PRINT 3001,TOTAL1
      PRINT 3002,TOTAL2
      PRINT 3003,TOTAL3
      PRINT 3004,TOTAL4
C
C
C
3001  FORMAT(/,3X,'DETECTOR OUTPUT AM MODULATION:',F4.1,' %',/)
3002  FORMAT(3X,'    AUDIO OUTPUT AM MODULATION: ',F4.1,' %',/)
3003  FORMAT(3X,'150 HZ FILTER OUTPUT AM MODULATION: ',F4.1,' %',/)
3004  FORMAT(3X,' 90 HZ FILTER OUTPUT AM MODULATION: ',F4.1,' %',/)
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
C
C
C     CALLING CDI SUBROUTINE TO CALCULATE CDI WITH INTERFERENCE PRESENT
C
C
      CALL CDI(TOTAL4,TOTAL3,IFLAG)
C
      IF (IFLAG .EQ.1)RETURN
C
      PRINT 5600
5600  FORMAT(//,'    COMBINED CROSSMOD AND INTERMOD % MODULATION CALCULAT
     CIONS',//)
C
C
C
```

```
C
C      .......COMBINING THE EFFECTS OF BOTH CROSSMODULATION AND INTERMOD
C
C
       IF(SUMC.LT.1.)GO TO 944
       PRINT 945
945    FORMAT('     CROSSCOMPRESSION IS GREATER THAN 1.LARGE INTERFERENCE
      CPRESENT ,THIRD ORDER MODEL OVER PREDICTS AMT OF CROSSCOMPRESSION')
       RETURN
C
C
C
C      SUMC IS THE AMT OF COMPRESSION OF THE LOCALIZER SIGNAL CAUSED
C      CAUSED BY BRUTE FORCE INTERFERENCE
C
C      VARIABLE NAMES FOR CROSSMODULATION AM MOD:
C      XMOD1 IS THE % RMS AM MOD AT THE RECEIVER DETECTOR OUTPUT
C      XMOD2 IS % AT AUDIO OUTPUT
C      XMOD3 IS THE % AT 150 HZ FILTER OUTPUT
C       XMOD4 IS THE % AT THE 90 HZ FILTER OUTPUT
C
C
C
C      IFLAG IS SET TO 1 TO INDICATE THAT INTERFERENCE IS DUE TO
C      BOTH IM AND 'BRUTE FORCE'  EFFECTS.
944    IFLAG=1
C      IF SUMC IS GREATER THAN 1. XMOD1,ETC. ARE % AM MOD CONSIDERING
C      CROSSCOMPRESSION DUE TO BRUTE FORCE INTERFERENCE
       TOTAL1=SQRT((TOTAL1/(1.-SUMC))**2 +XMOD1**2)
       TOTAL2=SQRT((TOTAL2/(1.-SUMC))**2 +XMOD2**2)
       TOTAL3=SQRT((TOTAL3/(1.-SUMC))**2 +XMOD3**2)
       TOTAL4=SQRT((TOTAL4/(1.-SUMC))**2 +XMOD4**2)
       GO TO 2999
       END
C**********************************************************************
       SUBROUTINE CDI(AM90,AM150,ITEST)
C**********************************************************************
C
C
C
C      THIS SUBROUTINE COMPUTES THE RESULTING CDI WITH RMS AM MODULATION
C      OF AM90 AT THE 90 HZ TONE FILTER,AND AM150 RMS MODULATION AT
C      THE OUTPUT OF THE 150 HZ FILTER. AM90 OR AM150 DOES  NOT INCLUDE
C      THE 90/150 HZ LOC. SIGNAL.
C      AM90 AND AM150 ARE GIVEN AS % MODULATION.
       PRINT 10
10     FORMAT(/,1X,72('*'),/,' TO CALCULATE CDI TYPE I')
       READ 12,IFLAG
12     FORMAT(I1)
       IF(IFLAG.NE.1)RETURN
C
C
C
C
C
```

```
      PRINT 5000
5000  FORMAT(//,1X,72('*'),//,3X,'RECEIVER CDI',//)
      IF (ITEST.EQ.0)PRINT5004
      IF(ITEST .EQ.1)PRINT 5005
5004  FORMAT(5X,'INTERFERENCE DUE TO IM ONLY',/)
5005  FORMAT(5X,'INTERFERENCE DUE TO IM AND BRUTE FORCE EFFECTS',/)
      PRINT 5001
5001  FORMAT(6X,'CDI',12X,'CDI',/,5X,'WITHOUT',8X,'WITH',/,
     C3X,'INTERFERENCE',4X,'INTERFERENCE',/,6X,'(UA)',11X,
     C'(UA)',/)
C
C
C
      DO 5099 I=1,13
      CDI=15*I-105
C
C     CALCULATION OF DDM
      DDM=CDI*.155/150.
      OUT90=.20+DDM/2.
      OUT150=.20-DDM/2.
C     RMS OUTPUT OF 90/150 TONE FILTERS WITH INTERFERENCE PRESENT
C     ADDING THE INTERFERENCE SIGNALS AM90&AM150,AND CALCULATING RMS
C     VALUE OF THE FILTERS.
C
C
C
      OUT90=SQRT(OUT90**2+(AM90/100.)**2)
      OUT150=SQRT(OUT150**2+(AM150/100.)**2)
C     RESULTANT CDI
      CDINEW=(OUT90-OUT150)*150./.155
      PRINT5010,CDI,CDINEW
5010  FORMAT(/,5X,F5.1,10X,F5.1)
5099  CONTINUE
      PRINT 5098
5098  FORMAT(//,1X,72('*'))
      RETURN
      END
```

```
C**************************************************************************
      SUBROUTINE CONVOL   (I,J,K,SUMDET,SUMAUD,SUMOD,SUM15))
C**************************************************************************
C       THIS SUBROUTINE CALCULATES THE RMS VALUE OF THE DETECTED INTERMOD
C      APPEARING AT THE OUTPUT OF THE RECEIVER
C
        DIMENSION FREQ(20),FMOD(20),BETA(20)
C
      REAL MILE(20),POWER(20),FQDEV(20)
      REAL LEVEL(20)
      REAL AXB(1000),AXBFQ(1000)
C
      COMMON FQRCVR,XMOD1,XMOD2,XMOD3,XMOD4,SUMC,BW,FK3K1
      COMMON FREQ,LEVEL,FMOD,BETA
      COMMON MILE,POWER,FQDEV,NSTAT
C
C
C
C
C****************THE CROSS SPECTRUM OF TWO FREQUENCIES IS GENERATED   ***
C
C
C
C
C      THRESHOLD VALUE IS SET
       VALMIN=.01
C
C      INDEX IS THE NUMBER OF TERMS IN AXB
200       INDEX=1
C      A CHECK IS MADE TO SEE IF THE TWO FREQS ARE THE SAME
       IF(I.NE.J)GO TO 40
C
C
C............ GENERATION OF AXB WITH I=J  ..................
C
C
C
C      CONVOLVING A TONE MODULATED FM SIGNAL WITH ITSELF RESULTS
C      IN A SPECTRUM TONE MODULATED WITH TWICE THE MODULATION INDEX
C
C
C      CALCULATING THE NUMBER OF POSITIVE ORDERBESSEL FUNCTION TERMS
       MAX1=2.*BETA(I)+1
C      MAX2 IS THE NUMBER OF TERMS BOTH POS. AND NEG.;ADD 1 FOR J(0)
       MAX2=MAX1*2+1
       DO1040 LL=1,MAX2
       INC=LL-MAX1-1
       AXB(INDEX)= BESSEL(2.*BETA(I),INC)
C      FREQ AXBFQ(I) IS THE FREQUENCY IN KHZ RELATIVE TO 2*FREQ(I)
       AXBFQ(INDEX)=+INC*FMOD(I)
40     INDEX=INDEX+1
1040   CONTINUE
       GO TO 50
C
C
```

```
C...........END OF GENERATING AXB WITH I+J  ..............
C
C
C&&&&&&&&&&&&&  GENERATION OF AXB WITH I NOT EQUAL TO J &&&&&
C
C
C      CREATION OF THE CROSS MOD SPECTRUM OF TWO UNRELATED FREQS
C
C
C
49     MAX1=BETA(I)+1
       MAX2=BETA(J)+1
       MAX3=MAX1*2+1
       MAX4 =MAX2*2+1
       DO 50 LL=1,MAX3
       DO51 MM=1,MAX4
        INC1=LL-MAX1-1
       INC2=MM-MAX2-1
C       NOTE THAT THERE IS A IXJ TERM AND A JXI TERM IN AXB
C       HOWEVER THE SUBROUTINE  ONLY CALCULATES THE IXJ TERM AND
C       IN THE MAIN PROGRAM THE IM CARRIER LEVEL IS MULTIPLIED BY 2
C
C
C
       AXB(INDEX)=BESSEL(BETA(I),INC1)*BESSEL(BETA(J),INC2)
C       IF A TERM IS LESS THAN VALMIN IT IS DELETED.
C
C
       IF(ABS(AXB(INDEX)).LT.VALMIN)GO TO 51
C/
C/
C
C      FREQ AXBFQ(INDEX) IS THE FREQUENCY IN KHZ OF THE F(I)XF(J)TERM
C      RELATIVE TO THE FREQUENCY FREQ(I)+FREQ(J).
       AXBFQ(INDEX)=+INC1*FMOD(I)+INC2*FMOD(J)
C       INCREMENTING THE AXB POINTER
       INDEX=INDEX+1
51     CONTINUE
50     CONTINUE
C
C
C&&&&&&&&  END OF AXB GENERATION FOR I N.E. J  &&&&&&&&&&&
59     CONTINUE
C      NUMBER OF TERMS STORED IN ARRAY AXB
       MAXAXB=INDEX-1
C
C
C
C
C
C
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
C
C      THE RESULTANT SPECTRUM IS CONVOLVED WITH FREQ K
```

```
C
C
C
C      CALLING SORT PROGRAM TO SORT AXB ELEMENTS WITH ASCENDING FREQ
C      FREQ OF AXB(I) GIVEN BY AXBFQ(I)
       CALL SORT(AXB,AXBFQ,MAXAXB)
C
C
C
C
C      CHECKING TO SEE IF THE DIMENSION OF THE ARRAY AXB IS EXCEEDED
C
       IF(INDEX.GT.1000)PRINT 77
77     FORMAT('  *** DIMENSION EXCEEDED')
C**************************************************************
C
C
C      HIGH SPEED CONVOLUTION PART OF SUBROUTINE(I.E.ARITHMETIC IF
C      STATEMENTS USED)
C
1976   CONTINUE
C
C       RFQ IS THE FREQ OF THE IM CARRIER RELATIVE TO  RECEIVER FREQ
       RFQ=FREQ(I)+FREQ(J)-FREQ(K)-FQRCVR
C CONVERTING RFQ FROM MHZ TO KHZ
       RFQ=1000.*RFQ
C
C
C      IM TERM MUST HAVE A FREQ WITHIN THE LIMITS OF ENDLOW AND ENDHI
C      TO BE PASSED THRU THE IF SECTION OF THE RECEIVER
       ENDLOW=RFQ-BW/2.
       ENDHI=RFQ+BW/2.
C
C
C      INTIALIZING VARIABLES
C
       LAST=1
       SUMDET=0.
       SUMAUD=0.
       SUM90=0.
       SUM150=0.
C
C
C      MAX1 IS THE NO. OF POSITIVE ORDER BESSEL FUNCTION TERMS
C      FOUND USING R.O.T.
       MAX1=BETA(K)+1
C      TOTAL NO. OF TERMS ;ADD 1 FOR J(0) TERM
       MAX2=2*MAX1+1
C
C.....................
C
       DO 999 INC=1,MAX2
       KORDER=INC-MAX1-1
C      SETTING IFLAG TO 0 ;WHEN IFLAG=1,INTERMOD COMPONENT IS WITHIN
C      RECEIVER BANDWIDTH
```

```
      IFLAG=0
C
C     THE ARRAY AXB IS SEARCHED FOR AN INTERMOD TERM IN RCVR BW.
C
C
C-----------------------
      DO 99 INDEXX=1,MAXAXB
C     INCREMENT INDEXX UNTIL GET TO WHERE PREVIOUS K TERM INTERMOD
C     STARTED IN  LIST OF IXJ CROSS PRODUCT TERMS
      IF(INDEXX-LAST)99,20,20
C     COMPUTING INTERMOD FREQUENCY IN KHZ IN RELATION TO IM CENTER FREQ
20    FREQIM=AXBFQ(INDEXX)-KORDER*FMOD(K)
C
C     IF IFLAG=1,TEST TO SEE IF INTERMOD IS LESS THAN HIGH END OF
C     RECEIVER PASSBAND
      IF(IFLAG )21,22,21
C     INTERMOD IS WITHIN RCVR BW IF FREQIM IS LARGER THAN ENDLOW
22    IF(FREQIM-ENDLOW)99,23,23
C     THIS IS THE FIRST INTERMOD COMPONENT FORMED BY TERM K ORDER KINDEX
C     THAT FALLS WITHIN RECEIVER BANDWIDTH;SET IFLAG;SET LAST EQUAL TO I
C     INDEXX
23    IFLAG=1
      LAST=INDEXX
C     CHECK TO SEE IF INTERMOD IS TOO HIGH IN FREQ..LARGER THAN ENDHI
C     IF IT IS, NO OTHER TERMS IN AXB WILL PRODUCE AN IM TERM IN
C     THERECEIVER PASSBAND,INCREMENT KORDER
21    IF(FREQIM-ENDHI)25,25,991
C     CALCULATE RMS OUTPUT OF DETECTOR
25    OUTPUT=AXB(INDEXX)*BESSEL(BETA(K),KORDER)
C... DEBUG STATEMENTS......
C....        BBFQ=-FMOD(K)*KORDER
C....        BB=BESSEL(BETA(K),KORDER)
C....        PRINT 2999,INDEXX,KORDER,AXB(INDEXX),BB,OUTPUT,AXBFQ(INDEXX)
C....       C, BBFQ,FREQIM
C....2999    FORMAT(2X,2I4,6E6.3)
C
C
C     FFQQ IS THE IM FREQ RELATIVE TO DESIRED SIGNAL FREQ.
C
      FFQQ=FFQ+FREQIM
C
C
C     CALCULATING FILTERED MODULATION FACTORS FOR THE DETECTOR,
C     AUDIO,90,150 HZ FILTER FUNCTIONS
C
C
      SUMDET=(OUTPUT*FILDET(FFQQ))**2+SUMDET
      SUMAUD=(OUTPUT*FILAUD(FFQQ))**2+SUMAUD
      SUM90= (OUTPUT*FQ90(FFQQ))**2+SUM90
      SUM150=(OUTPUT*FQ150(FFQQ))**2+SUM150
99    CONTINUE
C-----------------------
C
C
C
```

```
C
      GO TO 999
991   CONTINUE
C     END OF INDEXING THRU AXB.TAKE ANOTHER TERM OF FREQ KAND BEGIN
C     INDEXING THRU AXB ARRAY AGAIN.
C
C
C
999    CONTINUE
C...............................
1820  CONTINUE
      SUMDET=SQRT(SUMDET)
      SUMAUD=SQRT(SUMAUD)
      SUM90=SQRT(SUM90)
      SUM150=SQRT(SUM150)
C
C
C
      RETURN
      END
C
C*************************************************************************
C
C
      REAL FUNCTION BESSEL(BETA,ORDER)
C*********************************************************************
C
C
C     THIS FUNCTION COMPUTES THE BESSEL FUNCTION FOR POSITIVE AND
C     NEGATIVE ORDERS.
C
C
C
       INTEGER  ORDER
      N=IABS(ORDER)
C     THE IBM SUBROUTINE TO CALCULATE THE BESSEL FUNCTION IS CALLED
C     THIS PROGRAM COMPUTES THE BESSEL FUNCTION  FOR BETA= X AND
C     ORDER=N.  THE RESULTANT BESSEL FUNCTION  IS BJ
C     THE  DESIRED ACCURACY IS D. IERR IS THE ERROR CODE
C     IERR=0 NO ERROR
C     IERR=1 N NEGATIVE
C     IERR=2 X IS NEGATIVE OR ZERO
C     IERR=3 REQUIRED ACCURACY NOT OBTAINED
C     IERR=4 RANGE OF N COMPARED TO X NOT CORRECT.
C
C
C     SEE THE IBM SSP MANUAL FOR DETAILS PAGE 367
      CALL BESJ(BETA,N,BJ,.001,IERR)
      BESSEL=BJ
      IF(ORDER.LT.0)BESSEL=(-1)**(IABS(ORDER))*BJ
      IF(ORDER.EQ.0.AND.BETA.LT..01)BESSEL=1.
      RETURN
C     DEBUG SUBTRACE
      END
C*************************************************************************
```

```
      SUBROUTINE SORT(AXB,AXBFQ,MAXAXB)
C*********************************************************************
      DIMENSION AXB(MAXAXB),AXBFQ(MAXAXB)
C
C     THIS PROGRAM BUBBLE SORTS AXBFQ ARRAY AND PUTS INTO ASCENDING
C     ORDER. AXB IS ALSO SORTED.
C
C
C     INITIALIZE VALUES OF LAST AND LATEST.LAST INDICATES THE FINAL
C     ENTRY TO BE CONSIDERED IN THE FORTH COMING PASS.LATEST INDICATES
C     THE POSITION OF THE MOST RECENT INTERCHANGE PERFORMED.
      LATEST=MAXAXB
2     LAST=LATEST
C
C
C
C     BEGIN PASS THRU ARRAY
C
      DO 4 J=2,LAST
C
      IF(AXBFQ(J-1).LE.AXBFQ(J))GO TO 4
C
C     PERFORM INTERCHANGE
C
      LATEST=J-1
      TEMP1=AXBFQ(J-1)
      TEMP2=AXB(J-1)
      AXB(J-1)=AXB(J)
      AXBFQ(J-1)=AXBFQ(J)
      AXB(J)=TEMP2
      AXBFQ(J)=TEMP1
C
C
C
4     CONTINUE
C
C
C
C     DETERMINE WHETHER ANY FUTHER PASSES ARE NECESSARY
      IF(LATEST.LT.LAST.AND.LATEST.GT.1)GO TO 2
C
C
      RETURN
      END
C*********************************************************************
      REAL FUNCTION FILDET(FREQ)
C*********************************************************************
C     THIS FILTER FUNCTION APPROXIMATES THE IF FILTER CHARACTERISTICS
C     I.F.OUTPUT OF THE DETECTOR
C
C
C
C     THIS IS THE REVISED DETECTOR FILTER FUNCTION 12/27
C
C
```

```
      FILDET=0.
      FREQQ=ABS(FREQ)
      IF (FREQQ.LT.  4.6)FILDET=.89*(1.-(FREQQ/10.3))
      IF (FREQQ.GE. 4.6.AND.FREQQ.LT.12.)FILDET=.46
      IF(FREQQ.GE.  12.0. AND.FREQQ.LT. 17.2)FILDET=.44*(1.-(FREQQ-12.0)
     C /5.2)
      IF(FREQQ.GE.17.2)FILDET=0.
C     THIS IS A NORMALIZING FACTOR
C     TO MAKE MAX FILDET=1.
      FILDET=1.124*FILDET
      RETURN
      END
C************************************************************************
      REAL FUNCTION FILAUD(FREQ)
C
C************************************************************************
C
C     THIS FUNCTION IS USED TO COMPUTE   THE FILTER FUNCTION OF A FREQ.
C     TERM OCCURING AT THE AUDIO OUTPUT OF THE RECEIVER.
C
C     REVISED 12/27
C
      FILAUD=1.
      FREQQ=ABS(FREQ)
      IF(FREQQ.LE.  .14)FILAUD=0.
      IF(FREQQ.GT. .14 .AND. FREQQ.LT . .73)FILAUD=(FREQQ-.14)/.59
      IF(FREQQ.GE.  .73 .AND. FREQQ.LT . 1.)FILAUD=1.
      IF(FREQQ.GE. 1. .AND.FREQQ.LT.2.)FILAUD=1.-(FREQQ-1.)*.6
      IF (FREQQ.GE.2. .AND. FREQQ.LT. 3.)FILAUD=.4-.25*(FREQQ-2.)
      IF(FREQQ.GE.3. .AND.FREQQ.LT. 6.)FILAUD=.15-(FREQQ-3.)*.05
      IF(FREQQ.GE. 6.)FILAUD=0.
      RETURN
      END
C***********************************************************************
      REAL FUNCTION FIL150(FREQ)
C
C************************************************************************
C
C     THIS FUNCTION IS USED TO COMPUTE THE FILTER FUNCTION OF A FREQ.
C     TERM OCCURING AT THE 150 HZ FILTER OUTPUT OF THE RECEIVER.
C     THIS IS A NORMALIZED FILTER FUNCTION,I.E. FIL150(150 HZ)=1.
C
      FIL150=1.
      FREQQ=ABS(FREQ)
      IF(FREQQ.LT..090)FIL150=0.
      IF(FREQQ.GT..138.AND.FREQQ.LT..155)FIL150=1.
      IF(FREQQ.GE..090.AND.FREQQ.LE..138)FIL150=(FREQQ-.090)/(.138-.09)
      IF(FREQQ.GE..155.AND.FREQQ.LT..182)FIL150=1.-(FREQQ-.155)/(.250-.1
     C55)
      IF(FREQQ.GE..182.AND.FREQQ.LT..238)FIL150=.72-.72*(FREQQ-.182)/(.3
     C4)-.182)
      IF(FREQQ.GE..238)FIL150=.47-.47*(FREQQ-.238)/(.500-.238)
      IF(FREQQ.GT..500)FIL150=0.
      RETURN
      END
```

```
C*************************************************************************
      REAL FUNCTION FIL90(FREQ)
C
C*************************************************************************
C
C     THIS FUNCTION IS USED TO COMPUTE THE FILTER FUNCTION OF A FREQ.
C     TERM OCCURING AT THE 90 HZ FILTER OUTPUT OF THE RECEIVER.
C      IT  IS A NORMALIZED FILTER OUTPUT FUNCTION
C
      FREQQ=ABS(FREQ)
      IF(FREQQ.LT..058)FIL90=0.
      IF(FREQQ.GE..058.AND.FREQQ.LT..090)FIL90=(FREQQ-.058)/(.090-.058)
      IF(FREQQ.GE..090.AND.FREQQ.LE..095)FIL90=1.
      IF(FREQQ.GT..095.AND.FREQQ.LE..115)FIL90=1.-(FREQQ-.095)/(.238-.09
     C5 )
      IF(FREQQ.GT..115.AND.FREQQ.LT..160)FIL90=.7-.7*(FREQQ-.115)/(.160-
     C .115)
      IF( FREQQ.GT..160)FIL90=.45-.45*(FREQQ-.160)/(.430-.160)
         IF(FREQQ.GT..430)FIL90=0.
      RETURN
      END
C*************************************************************************
      REAL FUNCTION EQ90(FREQ)
C*************************************************************************
C
C
C
C     THIS FILTER FUNCTION HAS THE NOISE EQUIVALENT BW OF THE 90 HZ
C     FILTER. IT IS USED FOR IM CALCULATIONS ONLLY.
C      THE FILTER HAS A BW OF 336 HZ, A NOISE EQUIVALENT BW OF 168 HZ
C     THE FUNCTION IS MOST ACCURATE  WHEN THE MODULATION INDEX IS
C     HIGH AND THE MODULATION FREQ IS LOW .I.E. THE IM  LOOKS NOISE LIKE
C
C
C
      EQ90=0.
      IF(ABS(FREQ) .GT. .040 .AND. ABS(FREQ) .LT. .376)EQ90=.707
      RETURN
      END
C*************************************************************************
C
      REAL FUNCTION EQ150 (FREQ)
C
C*************************************************************************
C
C
C
C     THIS FUNCTION IS THE  NOISE EQUIVALENT FILTER OF THE 150 HZ FILTER
C     IT HAS AN EQUIVALENT BW OF 265 HZ
C     IT IS ONLY USED IN IM CALCULATIONS.
C
C
C
      EQ150=0.
      IF(ABS(FREQ).LT. .475.AND. ABS(FREQ).GT. .070)EQ150=.707

      RETURN
      END
```